



# NONRESIDENT TRAINING COURSE

January 2002



# Naval Space

NAVEDTRA 14168A



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# PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

**COURSE OVERVIEW:** This Nonresident Training Course (NRTC) is a self-study course that will acquaint officers and enlisted personnel with the history of the Navy in space and current civil and military space organizations. The course also provides the student with a basic understanding of the space environment, orbital mechanics, launch and recovery systems, space systems architecture, the naval tactical use of space, and foreign space programs.

Chapter 4, Orbital Mechanics, contains the technical information required by the student to comprehend the forces required to orbit a spacecraft and sustain that orbit. To assist you with this chapter, there is a supplemental 35 1/2-minute video, entitled *Space Flight: The Application of Orbital Mechanics*. The film, which was jointly produced by the Naval Space Command and the National Aeronautics and Space Administration, is available in all formats (3/4", VHS, Beta) and can be acquired through the Fleet Audiovisual Libraries. It is also available at no cost through the Defense Audiovisual Information System Product Identification Number 804859DN).

**THE COURSE:** This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068.

**VALUE:** In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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## **Sailor's Creed**

"I am a United States Sailor.

I will support and defend the  
Constitution of the United States of  
America and I will obey the orders  
of those appointed over me.

I represent the fighting spirit of the  
Navy and those who have gone  
before me to defend freedom and  
democracy around the world.

I proudly serve my country's Navy  
combat team with honor, courage  
and commitment.

I am committed to excellence and  
the fair treatment of all."

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# INSTRUCTIONS FOR TAKING THE COURSE

## ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

## SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

## SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

**Grading on the Internet:** Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the

assignments. To submit your assignment answers via the Internet, go to:

**<https://courses.cnet.navy.mil>**

**Grading by Mail:** When you submit answer sheets by mail, send all of your assignments at one time. Do NOT submit individual answer sheets for grading. Mail all of your assignments in an envelope, which you either provide yourself or obtain from your nearest Educational Services Officer (ESO). Submit answer sheets to:

COMMANDING OFFICER  
NETPDTC N331  
6490 SAUFLEY FIELD ROAD  
PENSACOLA FL 32559-5000

**Answer Sheets:** All courses include one “scannable” answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

**Do not use answer sheet reproductions:** Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

## COMPLETION TIME

Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.

## **PASS/FAIL ASSIGNMENT PROCEDURES**

If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment--they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

## **COMPLETION CONFIRMATION**

After successfully completing this course, you will receive a letter of completion.

## **ERRATA**

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

**<https://www.advancement.cnet.navy.mil>**

## **STUDENT FEEDBACK QUESTIONS**

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail. If you write or fax, please use a copy of the Student Comment form that follows this page.

## **For subject matter questions:**

E-mail: [bwatson@nsc.navy.mil](mailto:bwatson@nsc.navy.mil)  
Phone: Comm: (540) 653-5151  
DSN: 249-5151  
FAX: (540) 249-2949  
(Do not fax answer sheets.)  
Address: COMMANDER  
NAVAL SPACE COMMAND  
CODE VN7121  
5280 4TH STREET  
DAHLGREN, VA 22448-5300

## **For enrollment, shipping, grading, or completion letter questions**

E-mail: [fleetservices@cnet.navy.mil](mailto:fleetservices@cnet.navy.mil)  
Phone: Toll Free: 877-264-8583  
Comm: (850) 452-1511/1181/1859  
DSN: 922-1511/1181/1859  
FAX: (850) 452-1370  
(Do not fax answer sheets.)  
Address: COMMANDING OFFICER  
NETPDTC N331  
6490 SAUFLEY FIELD ROAD  
PENSACOLA FL 32559-5000

## **NAVAL RESERVE RETIREMENT CREDIT**

If you are a member of the Naval Reserve, you may earn retirement points for successfully completing this course, if authorized under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 5 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty*, BUPERSINST 1001.39, for more information about retirement points.)

## **Student Comments**

**Course Title:** Naval Space

**NAVEDTRA:** 14168A **Date:** \_\_\_\_\_

**We need some information about you:**

Rate/Rank and Name: \_\_\_\_\_ SSN: \_\_\_\_\_ Command/Unit \_\_\_\_\_

Street Address: \_\_\_\_\_ City: \_\_\_\_\_ State/FPO: \_\_\_\_\_ Zip \_\_\_\_\_

**Your comments, suggestions, etc.:**

<p><b>Privacy Act Statement:</b> Under authority of Title 5, USC 301, information regarding your military status is requested in processing your comments and in preparing a reply. This information will not be divulged without written authorization to anyone other than those within DOD for official use in determining performance.</p>
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NETPDTC 1550/41 (Rev 4-00)



# CHAPTER 1

## THE NAVY IN SPACE

“A globally-deployed Navy today needs space systems to make fleets out of ships. Today—and increasingly tomorrow—a seafaring nation must be a spacefaring nation.”

Admiral James D. Watkins, USN  
Chief of Naval Operations  
October 1, 1983, at the Inauguration  
of the Naval Space Command



## **INTRODUCTION**

Space and space operations are not new concepts to the Navy. The U.S. Navy's involvement in space spans four decades. During this time, the U.S. Navy has been a leader in developing national space capabilities, pioneering many of the early programs from launching satellites to placing a man on the moon. This involvement is continuing at an accelerated pace with significant implications for future Naval operations.

In this chapter we will review the Navy's involvement in space from its early accomplishments through current programs and capabilities. Topics covered include:

- Global Requirements;
- History of Naval Research and Development;
- U.S. Naval Satellite Systems;
- U.S. Naval Contributions to the Manned Space Program.

## **GLOBAL REQUIREMENTS-A NAVAL HERITAGE**

The U.S. Navy has evolved since colonial times into a truly "blue water navy," with responsibilities that span the globe. This global presence has spawned operational requirements for worldwide navigation, environmental monitoring, and communication capabilities. The ability to operate in a coordinated fashion across vast distances continues to be at the foreground of naval requirements.

By far the most exciting development has come in just the last few decades with the exploitation of the fourth military arena, the "high ground" of space. Being so dependent on long-range communications, weather forecasting, and navigation, it's easy to see why the Navy remains the primary tactical user of space assets. The Navy's longtime commitment to research and scientific problem solving led to such developments as radio, radar, satellites to provide global connectivity, and manned space flight. The Navy has earned its place in history as a pioneering service in the development and exploitation of space.

## **NAVIGATION AND THE EARLY MARINERS**

Accurate navigation has been a continuing naval requirement. Since time immemorial, man has put to sea in ships. Early mariners stayed within sight of the coastline for fear of losing touch with the land. Trade and exploration were at the mercy of coastal breezes and contained dangers of tidal currents, rocks, and shoals. Ancient charts were rudimentary and not widely circulated. As the "known world" expanded, these limitations were pushed back by new navigational techniques but progress was slow.

Caravans navigated by stars across vast expanses of desert. They had the advantage of gauging their progress in terms of days and distance traveled without having to guess at the influence of currents and winds. They used geographic landmarks for

reference along the way. At sea, the Phoenicians, Greeks, Romans, Vikings, and South Sea Islanders also became masters at using the stars to aid in navigation. The stars were used to estimate latitude. Calculating longitude remained a problem because of the rotation of the Earth.

### **Science and Technology, a Naval Tradition**

Much tradition of the United States Navy originated with the British Royal Navy. Part of this heritage is in the use of science and evolving technologies to solve operational problems. The Royal Navy recognized the need for precise navigation across the world's oceans. Determining latitude required only the Sun or the North Star, but calculating longitude required precision timekeeping.

Clocks of that day were too large, expensive, and cumbersome to be considered for shipboard use. Most were so inaccurate that they didn't even have a second hand, and accuracy of the minute hand was in question. In 1725, the Board of Longitude offered a prize of ten thousand pounds to sponsor the development of a chronometer that would be reliable for long voyages (from England to the West Indies and return), was small and rugged enough to take aboard the small sailing vessels of the day, and was accurate to 1° of longitude.

The British Royal Navy also recognized the need to produce charts of the known world and accurate tables of star motion for use by navigators. The Royal Naval Observatory at Greenwich, England, and later the U.S. Naval Observatory in Washington, D.C., became world-recognized authorities at precisely measuring and standardizing time and building accurate celestial tables. Celestial navigation is still widely used by ocean-going ships and long-range aircraft as a backup for more sophisticated electronic methods. Once these three enabling factors—accurate charts, celestial tables, and precision timekeeping—came together, accurate navigation was possible for the first time.

In the United States, research and development continued in these areas at an accelerated pace and more than forty years ago the Navy quickly realized that space is essential to naval operations. In response to the increasing dependence on space systems to conduct military operations and the rapidly growing need for expertise in this field, the Naval Postgraduate School established the Space Systems Academic Group. The Group's objective is to enable the graduate to develop the requirements, strategy, and doctrine necessary to plan and manage military space systems. To accomplish this objective, the program of study provides officers with a comprehensive operational and technical understanding of Navy Space Systems at the graduate level. Graduates acquire the practical and theoretical skills in space operations required to advance the combat effectiveness of our Naval force.

## **INITIAL NAVY SPACE RESEARCH**

The Naval Research Laboratory (NRL), was initiated by Secretary of the Navy, Josephus Daniels, in 1915. With Thomas A. Edison's support, it was dedicated in 1923 in Washington, D.C. Its mission was to blend scientific research with naval requirements.

The Naval Research Lab's initial work involved the development of dependable, long-range communications for the fleet in the days following World War I (WWI). Airborne Early Warning Radar, perhaps the labs' most celebrated scientific achievement, was demonstrated in 1934. Other technologies invented and developed at NRL revolutionized warfare in World War II (WWII) and subsequent conflicts. NRL also developed initial satellite tracking schemes. These were later exploited by the Naval Space Surveillance Center (NAVSPASUR) in the form of a radar fence across the continental United States' 33rd parallel.

### **Early Navy Pioneers**

Daniel Guggenheim, a WWI naval aviator, saw the Navy's need to stay abreast of the state of the art in science and technology. He helped sponsor Dr. Robert H. Goddard's early work in rocketry in Roswell, New Mexico, and later lent his expertise to the Navy during WWII. Goddard assisted a naval rocketry pioneer, Robert C. Truax, with his research and development work in guided missiles. Truax's 1938 research into a combined gasoline/compressed-air rocket engine led to the development, in 1942, of jet assisted takeoff (JATO) for aircraft. JATO was used extensively to aid heavyweight aircraft and seaplanes in making short field takeoffs. During the post-war period, this laid the groundwork for the use of rocket power in Navy guided missiles.

### **Preliminary Concepts**

By 6 November 1945, CDR Harvey Hall and LT Robert DeHavilland, both assigned to the Navy's Bureau of Aeronautics, proposed the construction and launch of an Earth satellite for scientific purposes. The satellite project, called HATV (High Altitude Test Vehicle), consisted of a single-stage, liquid oxygen/hydrogen rocket capable of achieving orbit. The stainless steel craft was to have nine individual motors producing up to 300,000 of pounds thrust at altitude. CDR Hall and LT DeHavilland shared this proposal with the Army Air Force at a meeting in Washington, D.C., on 7 March 1946. The Army Air Force, hoping to inspire a joint effort, asked the RAND Corporation (a government think tank) to come up with a study on the feasibility of an Earth satellite.

On 12 May 1946, the RAND Corporation reached two prophetic conclusions:

- A satellite with appropriate instrumentation could be one of the most potent scientific tools of the 20th century;
- A United States satellite would inflame the imagination of the world.



"To visualize the impact," the study stated, "one can imagine the consternation and admiration that would be felt here if the United States were to discover, suddenly, that some other nation had already put up a successful satellite. This prophecy came to pass in October 1957 when the Soviet Union launched Sputnik.

### **Navy Rocket Research**

After WWII, the Naval Research Lab was one of the first government agencies to seriously commit to exploring the upper atmosphere. Previous studies had been limited to adventurous efforts performed by pioneering pilots in airplanes. The NRL was quick to realize the benefits of the new field of rocketry. The lab initiated research and development programs to capitalize on this evolving technology. They proposed using captured German V-2 rockets to conduct studies of the upper atmosphere and to develop their own rocket, the *Viking*.

Following this proposal, the Viking rocket was based on the V-2 and had a small upper stage called the *Aerobee*. Six *Vikings* flew from the decks of ships, including the aircraft carrier Midway, and the National Aeronautics and Space Administration's (NASA) test range at Wallops Island, VA, through 1950. These tests not only advanced our knowledge of the upper atmosphere but they also laid the foundation for operational development of ballistic missile programs that were to follow. The vision of sea-launched ballistic missiles became a reality in the late 1950s with the advent of nuclear-powered submarines.

### **Early Satellites**

By the 1950's, just as the RAND report had forecast, the military implications of space became obvious. Satellites have played a major role in national defense since then. The U.S. Navy's preliminary efforts to develop space capabilities were at the focal point of our Nation's rush to exploit the "Final Frontier."

**PROJECT ORBITER.** In 1955, initial efforts at interservice cooperation between the Navy and Army on satellite programs resulted in Project Orbiter. The program's objective was to orbit a series of small, 5-pound, fully instrumented satellites. The Navy would be responsible for developing the satellites while the Army would have the responsibility for launching them. This joint service project proceeded until President Eisenhower announced that the United States would launch, for scientific purposes, small, unmanned, Earth-orbiting satellites as part of our contribution to the International Geophysical Year (IGY) of 1957-58. Although the military implications were obvious, the President was emphatic that this be a civilian, scientific effort—thus Project Orbiter was canceled in favor of the IGY initiative.

**PROJECT VANGUARD** proposed by the NRL was chosen to proceed in 1955. The Army and Air Force would provide support in the form of launch and tracking facilities, while the Navy would provide the launch vehicle. It was a very ambitious program. The technical challenges required integrating three different prototype rocket

stages into a single-launch vehicle, as well as the programmatic difficulties of engineering the interfaces and infrastructure of a fledgling space program. All to be accomplished within a two year period.

The Navy's *Viking* rocket was chosen as the launch vehicle for Project Vanguard. All the Navy's existing test facilities at the White Sands Missile Test Range in New Mexico were dismantled and transported to their new operating location at Cape Canaveral, FL. By 4 October 1957, Project Vanguard had successfully launched two test missions and was preparing for the final test flight when the Russians announced the successful launching of Sputnik. The "space race" had begun. The final Vanguard dress rehearsal occurred later that same month.

By December, Project Vanguard was ready to orbit a satellite; unfortunately, the rocket exploded shortly after liftoff. On 31 January 1958, the Army Ballistic Missile Agency sponsored *Explorer* satellite, headed by Werner Von Braun, became the United States' first successful satellite to be launched into space. One more failure of the *Viking* rocket in February 1958 preceded the successful launch of the 3.25-pound, 6 inch magnesium sphere, *Vanguard I*, on 17 March 1958, to a 406 x 2,465 mile Earth orbit. *Vanguard I* remains in orbit to this day circling the globe every 133 minutes, providing valuable data about the earth's true geometry.

Despite a troubled beginning, the Navy learned a great deal about space systems engineering and operations and demonstrated its ability to successfully integrate complex systems and technologies. For example, *Vanguard* was the first spacecraft to use solar cells in addition to batteries for electrical power to drive its scientific instruments and radio transmitter. NRL's efforts to develop a worldwide tracking network for *Vanguard* led to establishment of the Naval Space Surveillance Center (NAVSPASUR) for satellite tracking in 1961. Additionally, over 200 of the Navy's best and brightest scientists and engineers were chosen as part of the initial cadre to form the National Aeronautics and Space Administration (NASA) in July 1958.

## **Operational Satellites**

On April 13, 1960, the nation's first operational satellite system and the world's first navigational satellite, the Navy's TRANSIT 1B, went into orbit on a Thor-Delta rocket. Developed by Johns Hopkins University Applied Physics Laboratory and the NRL, TRANSIT provided the capability for ships to calculate their position to within half a nautical mile. This technology proved that an operational satellite system would permit atomic submarines to cross an ocean without surfacing and navigate difficult waters like the Strait of Gibraltar. Surface ships could also determine their positions at any time or in any weather and ply the seas with greater efficiency and safety.

The Naval Astronautics Group (renamed the Naval Satellite Operations Center [NAVSOCC]) was established in 1962 at Point Mugu, CA, to operate and maintain the TRANSIT constellation of satellites. No longer used by the U.S. Navy, these satellites are still in service providing 24 hour, all-weather, navigational data to a host of

worldwide users. TRANSIT pioneered the operational use of space for navigation. The current NAVSTAR Global Positioning System (GPS), an outgrowth of the NRL's work on the Naval Space Surveillance System, is the successor to TRANSIT.

As forecast by the RAND report, development of meteorological, communications, and surveillance satellites was also underway during the early 60s and the Navy was quick to exploit their capabilities. These satellites and their missions are discussed in chapter 7.

## **MANNED SPACEFLIGHT**

Just as early naval aviators pioneered the development of the airplane, naval test pilots became the pioneers of the manned space era.

### **X-15 ROCKET PLANE**

Constructed by North American Aviation, the X-15 was the nation's first serious attempt at manned flight outside the atmosphere. First drop-launched from a B-52 in 1959, the X-15 was soon routinely flying far beyond the design limits of conventional aircraft.

The X-15 rocket plane was the first manned vehicle to explore the fringes of space at speeds up to 4,520 mph (Mach~6.7) and altitudes to 354,200 feet. Naval aviators such as Forrest Peterson, Neil Armstrong, Scott Crossfield, and Milton Thompson participated in many of the X-15's 199 flights. These test flights resolved many questions concerning hypersonic flight and led the way for the manned space program. After successfully accomplishing program objectives, the X-15 program was terminated in 1968.

### **PROJECT MERCURY**

NASA began Project Mercury in 1959 as an offshoot of the United States' "Man In Space Soonest" project. The purpose of the project was to close the space gap that had developed with the Russians after their successful launch of Sputnik. Project Mercury was the United States' first attempt at manned space flight. The Project's major goal was to demonstrate that man could fly in space and return safely to Earth. The program goals were specific:

- To orbit a manned spacecraft around the Earth;
- To investigate man's ability to function in space; and
- To recover both man and spacecraft safely.

The United States was once again eclipsed by the Soviets when Yuri Gagarin made the first manned space flight on 12 April 1961. Project Mercury was successful however in accomplishing its objectives and was instrumental in narrowing the "space gap" between the Union of Soviet Socialist Republics and the United States.

The *Mercury* spacecraft built by McDonnell was as modest as the project's goal itself. A single-seat craft, it had been designed by a NASA engineer, Dr. Maxime Faget, during a coast-to-coast flight in a DC-3. Faget, a former naval officer in submarine service during WWII never forgot the KISS (keep it simple, stupid) principle during the design process. This same spacecraft evolved from a sub-orbital vehicle lofted into space by a Redstone rocket (Figure 1-1) for a 15 minute flight into an orbital craft that spent more than 34 hours in space.

Project Mercury ended in May 1963, after completing six successful manned missions and establishing the fact that humans could safely function in the hostile environment of space. The United States had now joined the battle for the high ground of space. Of the original seven astronauts (Figure 1-2), four were naval aviators (Table 1-1).

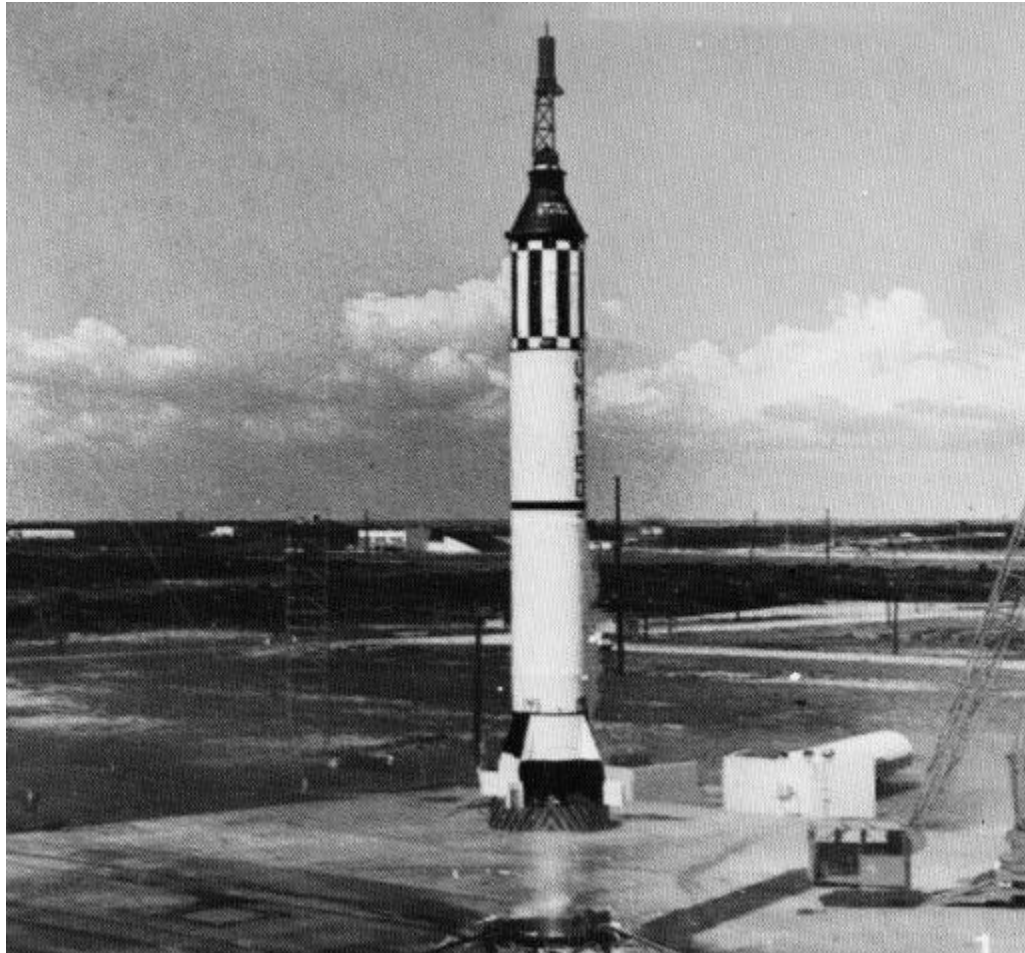


Figure 1-1. Redstone rocket.



Figure 1-2. The seven original NASA astronauts.

<b>Table I-1. Naval Aviators in Project Mercury</b>			
<b>Date</b>	<b>Mission Designation</b>	<b>Naval Astronaut(s)</b>	<b>Mission Accomplishments</b>
05 May 1961	Mercury 3	Alan B. Shepard, USN	First U.S. manned space flight. Demonstrated the ability to achieve manual control under weightlessness.
20 Feb 1962	Mercury 6	John H. Glenn, USMC	First American to orbit the earth. Three orbits lasting nearly 5 hours.
24 May 1962	Mercury 7	M. Scott Carpenter, USN	Three orbits lasting nearly 5 hours.
03 Oct 1962	Mercury 8	Walter M. Schirra, Jr., USN	Six orbits lasting 9 hours, 13 minutes.

## PROJECT GEMINI

The second U.S. manned. space program was announced in January 1962. Its two man crew gave the program its name, *Gemini* for the third constellation of the Zodiac and its twin stars, Castor and Pollux. Project Gemini involved a total of twelve flights, two of which were unmanned.

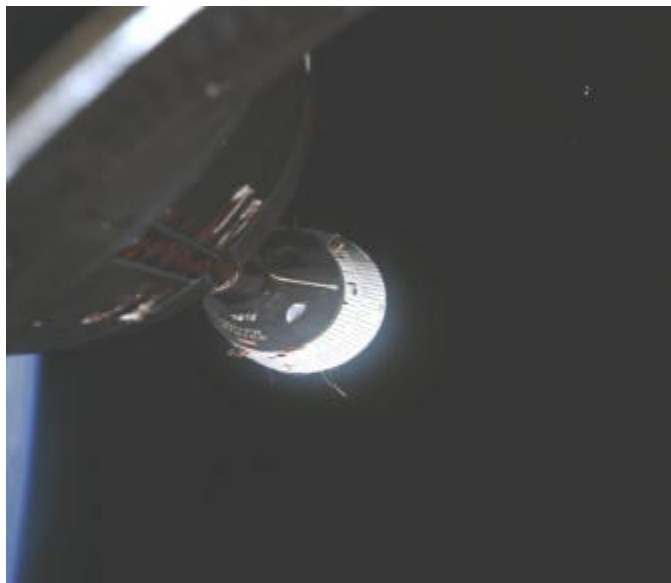


Figure 1-3. Gemini VII spacecraft from Gemini 7/6 Rendezvous 15 December 1965.

Project Gemini's purpose was to demonstrate the technologies and operations necessary to achieve the goal that President John F. Kennedy set for the nation-to make a manned lunar landing and return safely. Complex navigation rendezvous with other spacecraft, and expanding the duration of manned missions were among the highest priorities of Project Gemini. Like Project Mercury, *Gemini's* objectives were clear-cut:

- To subject two crew members and supporting equipment to long duration flights (a requirement for projected later trips to the moon or deep space);
- To rendezvous and dock with other orbiting vehicles in space;
- To perfect methods of reentry and landing the spacecraft at a pre-selected landing point on Earth; and
- To gain additional information concerning effects of weightlessness on crew members and to record the physiological reactions of crew members during long duration flights.

The two-seat *Gemini* spacecraft, shown in Figure 1-3, was built by McDonnell and took advantage of Project Mercury's many lessons learned; it had ejection seats, more cabin space, was more maneuverable, and had more propellant. A state-of-the-art radar was installed to help accomplish the most ambitious of goals: rendezvous and docking. Extravehicular activity (EVA) and space walks were also to be demonstrated. To accommodate all these improvements and embark upon a more ambitious orbital flight test program, the Atlas rocket of the later *Mercury* flights was replaced by the Titan II rocket (see Figure 1-4). The accomplishment of all of these goals was necessary to make a lunar landing.



Figure 1-4. Gemini VIII launch 11:41 am. (EST).

Project Gemini spanned a twenty-month period from March 1965 to November 1966, with ten manned missions. Included among the second and third groups of astronauts were 11 naval aviators: LCDR Charles "Pete" Conrad, LCDR James Lovell, LCDR John Young, LCDR Alan Bean, LCDR Eugene Cernan, LCDR Roger Chaffee, LCDR Richard Gordon, CAPT Clifton Williams, former naval aviator Neil Armstrong, and former Marines Elliot See, and Walter Cunningham. These astronauts formed the nucleus of future Apollo crews (see table 1-2). Their accomplishments in Project Gemini set the stage for the Project Apollo lunar missions.

<b>Table 1-2. Project Gemini Naval Astronauts</b>			
<b>Dates</b>	<b>Mission Designation</b>	<b>Naval Astronaut(s)</b>	<b>Mission Accomplishments</b>
23 Mar 1965	Gemini 3	John W. Young, USN	First U.S. two-man space mission; first spacecraft to maneuver from one orbit to another; 3 Earth orbits.
21 to 29 Aug 1965	Gemini 4	Charles Conrad, USN	Demonstrated man's ability to function in the space environment for long periods; used fuel cells for electrical power and evaluated guidance and navigation system for future rendezvous missions.
04 to 18 Dec 1965	Gemini 7	James A. Lovell, USN	World's longest manned space flight to date (over 330 hours); record to stand until the Skylab mission a decade later.
15 to 16 Dec 1965	Gemini 6	Walter M. Schirra, Jr., USN and Thomas P. Stafford, USAF (USNA Graduate)	First manned space rendezvous; maneuvered to within about 1 foot of the Gemini 7 spacecraft; 16 Earth orbits.
16 Mar 1966	Gemini 8	Neil A. Armstrong (former naval aviator)	First docking between a manned spacecraft and an unmanned space vehicle.
03 to 06 Jun 1966	Gemini 9	Eugene A. Cernan, USN and Thomas P. Stafford, USAF (USNA graduate)	Rendezvoused with Augmented Target; docking was not accomplished due to mechanical failure.
18 to 21 Jul 1966	Gemini 10	John W. Young, USN	First use of target vehicle, <i>Agena</i> , as source of propulsion after docking; setting a new altitude record for manned spacecraft of 474 miles.
12 to 15 Sep 1966	Gemini 11	Charles Conrad, Jr., USN and Richard F. Gordon, Jr., USN	Achieved first orbit rendezvous and docking with <i>Agena</i> target vehicle; used the <i>Agena</i> to boost Gemini 11 to a record altitude of 850 miles; during an EVA, Gordon fastened <i>Agena</i> -anchored tether to Gemini docking bar, and spacecraft later made two Earth orbits in a tethered configuration.
11 to 15 Nov 1966	Gemini 12	James A. Lovell, USN	First solar eclipse photographed from space.



## Project Apollo

From the initial commitment to go to the Moon, it was obvious that very large boosters and very specialized spacecraft would be required to do the job. All during the *Mercury* and *Gemini* development flights, the Saturn series of super boosters (shown in Figure 1-5), the *Apollo* Command and Service Module (CSM), and the Lunar Excursion Module (LEM), (shown in Figure 1-6), were under development. All flight hardware had to be rigorously tested and qualified.



Figure 1-5. Apollo 16 Liftoff.



Figure 1-6. Astronaut Young salutes flag at Apollo 16 DESCARTES Landing Site.

In January 1967, as the first *Apollo* CSM was being checked out by its flight crew, a fire broke out in the pure oxygen atmosphere of the capsule. "Gus" Grissom, CDR Roger Chaffee, and Ed White were killed. The investigations led to design changes to the *Apollo* CSM, as well as to the rest of the *Apollo* program. The delay resulted in a safer, more system-redundant spacecraft.

An ambitious flight test program followed. Of 10 missions, only two development flights were constrained to Earth orbit. The first flight was *Apollo 7*, commanded by CAPT Wally Schirra; the second was the first flight of the Lunar Excursion Module on *Apollo 9*. Project Apollo was to see eight missions circle the Moon with six missions actually visiting the lunar surface (see Figure 1-7). Naval aviators again led the way. Their many accomplishments are shown in Table 1-3.

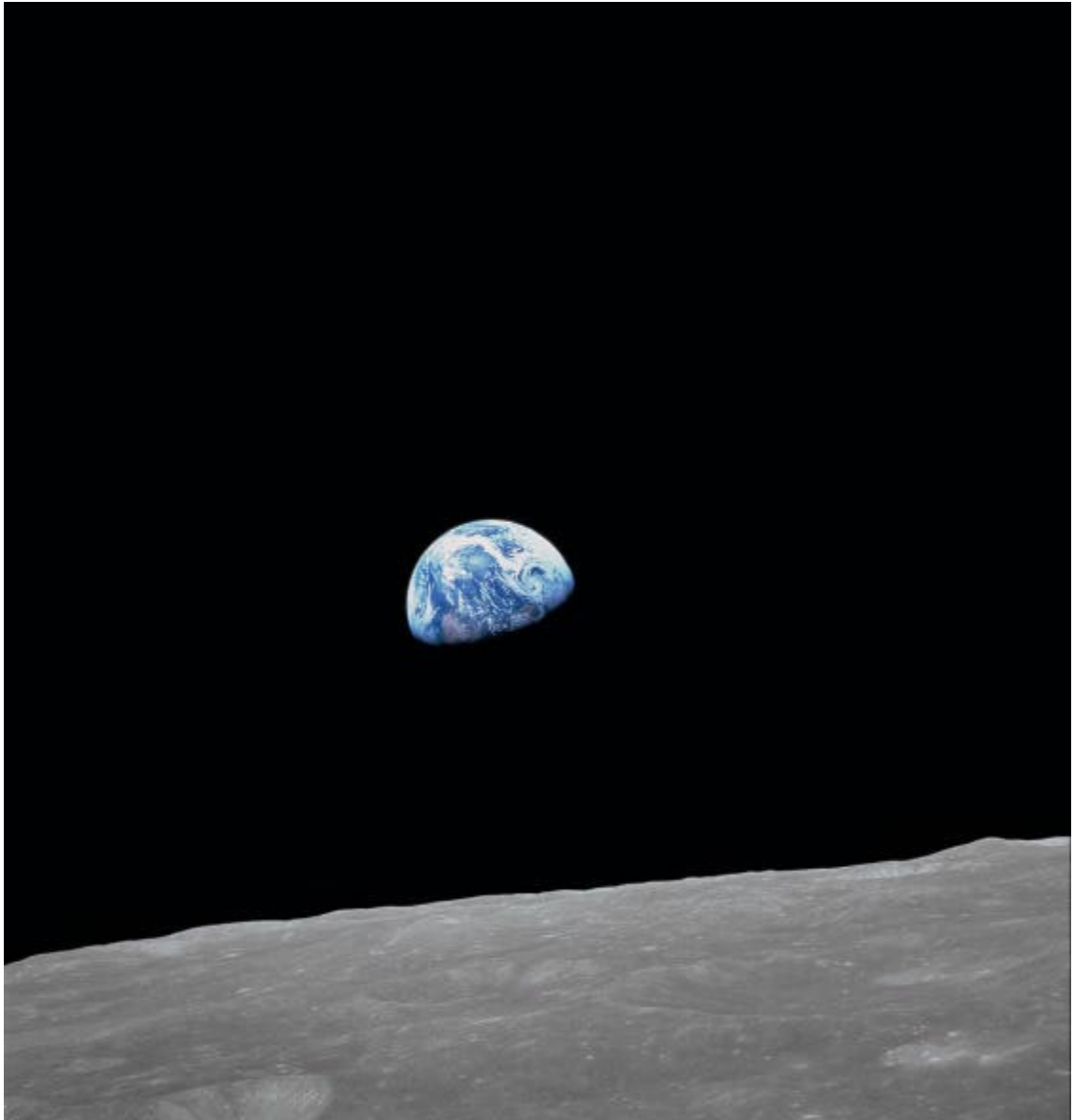


Figure 1-7. Apollo 8 spacecraft, in orbit around the moon, views the earth.

<b>Table 1-3. Project Apollo Naval Astronauts</b>			
<b>Dates</b>	<b>Mission Designation</b>	<b>Naval Astronauts</b>	<b>Mission Accomplishments</b>
11 to 22 Oct 1968	Apollo 7	Walter M. Schirra, Jr., USN and Walter Cunningham, USN	First manned mission of Apollo program; demonstrating the ability of space flight network to conduct Earth orbital mission; live TV broadcast from space.
11 to 27 Dec 1968	Apollo 8	John W. Young, USN, Eugene A. Cernan, USN, and Thomas P. Stafford, USAF (USNA graduate)	Full dress rehearsal for manned lunar landing; demonstrating LEM rendezvous and docking with CSM; confirming all aspects of lunar landing procedures except actual descent; Stafford and Cernan flew LEM to within 9.4 miles of lunar surface
16 to 24 Jul 1969	Apollo 11	Neil A. Armstrong, Civilian (Former naval aviator)	First manned lunar landing; the LEM descended to the lunar surface where astronauts Armstrong and Aldrin spent 21.5 hours deploying scientific instruments and collecting samples.
14 to 24 Nov 1969	Apollo 12	Charles Conrad, Jr., USN, Richard F. Gordon, Jr., USN, and Alan L. Bean, USN	Second manned lunar mission; Conrad and Bean made a pin-point landing in the Ocean of Storms within walking distance of the Surveyor 3 lunar probe; in two EVAs astronauts set out scientific instruments, collected lunar samples, and removed TV camera and other parts from Surveyor for examination on Earth.
11 to 17 Apr 1970	Apollo 13	James A. Lovell, USN	Mission aborted after an explosion of fuel cell's oxygen tank in CSM 205,000 miles from Earth while approaching the moon; astronauts were successfully recovered.
31 Jan to 09 Feb 1971	Apollo 14	Alan B. Shepard, USN, and Edgar D. Mitchell, USN	After separating from CSM in lunar orbit, Shepard and Mitchell landed in hilly upland region north of Fra Mauro crater; total stay on the moon was 33.5 hours.
26 Jul to 07 Aug 1971	Apollo 15	James B. Irwin, USAF (USNA graduate)	Irwin and David R. Scott landed lunar module near Apennine Mountains region; astronauts performed three EVAs using Lunar Roving Vehicle (LRV) for first time; LRV traveled a total of 17.3 miles; first live TV coverage of LEM ascent stage lift-off from the moon.
16 to 27 Apr 1972	Apollo 16	John W. Young, USN, Thomas K. Mattingly, USN, and Charles M. Duke, USAF (USNA graduate)	Sixth lunar landing mission; CSM released sub-satellite in lunar orbit.
07 to 19 Dec 1972	Apollo 17	Eugene A. Cernan, USN, and Ronald E. Evans, USN	Seventh and final lunar landing mission.

## Project Skylab

As the lunar program wound down, work was being completed on the upper stage of the Saturn V rocket for use as a space laboratory. The *Skylab* was designed to provide a shirtsleeve environment for astronauts to perform medical, Earth science, and astronomical observations.

*Skylab* got off to a shaky start when one of its two solar panels ripped away on launch and its remaining solar panel stuck closed. *Skylab's* first crew, an all Navy team (CAPT 'Pete' Conrad, CDR Paul Weitz, and CDR Joseph Kerwin), had their work cut out for them. The insulation designed to keep the laboratory from reaching intolerable temperatures had been torn away with the solar panel. Conrad maneuvered the *Apollo* spacecraft, while Weitz cleared away debris. A sunshade erected from the airlock, seen in Figure 1-8, reflected the sun's radiation enough to lower the onboard temperatures to normal. Weitz and Kerwin exited from the *Skylab* and performed a space walk, and freed the remaining solar panel, allowing completion of *Skylab's* planned missions.



Figure 1-8. Skylab space station cluster deployed in earth orbit.

Kerwin also had the distinction of being the first Navy Flight Surgeon to fly in space. The success of the medical experiments performed aboard *Skylab* on this 28-day mission remains a tribute to his naval background and training.

The second *Skylab* mission commanded by CAPT Alan Bean, USN, with LCOL Jack Loosma, USMC, and Dr. Owen Garriott as crewmembers, doubled the existing space-endurance record, spending 59 days in orbit. The third (an all-rookie crew) was commanded by LCOL Gerald Carr, USMC. When they de-orbited 84 days later, they set a space endurance record that was to stand until the late 1980s. The *Skylab* orbit decayed and the United States' first space station reentered the atmosphere in July 1979 over Australia. Despite its shaky start and fiery demise, *Skylab* provided an untold wealth of scientific data paving the way for future space stations.

<b>Table 1-4. Skylab Naval Astronauts</b>			
<b>Dates</b>	<b>Mission Designation</b>	<b>Naval Astronauts</b>	<b>Mission Accomplishments</b>
25 May to 22 Jun 1973	Skylab 2	Charles Conrad, Jr., USN,  Joseph P. Kerwin, USN, and  Paul J. Weitz, USN	First U.S. manned orbiting space station; during EVA astronauts erected sunshield and deployed stuck solar array wing; astronauts obtained data on 46 of 55 planned experiments and performed 3 EVAs totaling 5.75 hours; total flight time about 673 hours.
28 Jul to 25 Sep 1973	Skylab 3	Alan L. Bean, USN, and  Jack R. Lousma, USMC	New sunshield was deployed; rate gyros replaced; 3 EVAs performed totaling 13.75 hours; total flight time was 1,427 hours (2 months).
16 Nov to 08 Feb 1973	Skylab 4	Gerald P. Carr, USMC	Final Skylab visit; astronauts replenished coolant supplies, repaired antenna, and observed Comet Kohoutek; conducted 4 EVAs totaling 22.4 hours; set EVA duration record of 7 hours; total flight time was 2017.25 hours (84 days).



## Space Shuttle

Originally conceived in 1969, the Space Shuttle represented the first attempt to build a truly reusable, operational spacecraft to provide routine access to space. The Shuttle was designed by Rockwell and approved for construction in 1972. Atmospheric flight tests of the orbiter *Enterprise*, carried aloft by a modified Boeing 747 were conducted in 1977 and 1978.

The Space Transportation System (STS), or Space Shuttle (shown in Figure 1-9), is launched by two solid rockets and propelled into orbit by three reusable main engines fueled by liquid oxygen and liquid hydrogen. The fuel is housed in an expendable external tank. Figure 1-10 shows the first crew for the Space Shuttle Orbital flight test (STS-1).



Figure 1-9. Launching of Space Shuttle.



Figure 1-10. First crew (left-to-right: John W. Young, USN, and Robert L. Crippen, USN) for the Space Shuttle orbital flight tests (STS-1).

Intended to support both NASA civilian and Department of Defense (DOD) missions, the payload bay was sized to transport objects up to 15 feet in diameter and 60-feet long into orbit at a maximum acceleration of three g's. The modular aspects of the payload bay made for rapid reconfiguration between missions carrying vastly different cargoes.

Following *Columbia's* first flight in April 1981, the Shuttle compiled an impressive record of 24 successful missions deploying, retrieving, and repairing satellites. On January 28, 1986, the shuttle *Challenger* exploded shortly after launch, killing all seven astronauts aboard, including Navy CDR Michael Smith. The lengthy redesign that followed resulted in many improvements to the Shuttle and the program overall. As a result, the Shuttle remains a vital part of the NASA and DOD space plans.

As in previous manned programs, naval aviators played a leading role in the Shuttle program. Their many accomplishments are given in Table 1-5.



<b>Table 1-5. Space Shuttle Naval Astronauts</b>			
<b>Dates</b>	<b>Mission Designation</b>	<b>Naval Astronaut(s)</b>	<b>Mission Accomplishments</b>
12 to 14 Apr 1981	STS-1 (Columbia)	John W. Young, USN Robert L. Crippen, USN	First orbital test flight of Space Shuttle. All Navy crew. Crew tested opening and closing of cargo bay doors, emergency donning of pressure suits, and testing of basic systems. Orbiter completed planned 36 orbits and landed at Edwards AFB, Calif.
12 to 14 Nov 1981	STS-2 (Columbia)	Richard H. Truly, USN (1 <sup>st</sup> commander of the Naval Space Command)	Mission included five experiments mounted on pallet in the cargo bay to explore the Earth's natural resources. The crew also tested the Remote Manipulator System (RMS), a robotic arm used to deploy satellites from the cargo bay.
22 to 30 Mar 1982	STS-3 (Columbia)	Jack R. Lousma, USMC	Mission included instruments mounted on a pallet in the cargo bay devoted to astronomy and space physics. The crew also tested the RMS by removing and replacing a payload in the cargo bay.
27 Jun to 04 Jul 1982	STS-4 (Columbia)	Thomas K. Mattingly, USN	Fourth and final orbital test of Space Shuttle. Mission objectives included investigating the Orbiter's capability under extreme in-orbit conditions of solar heating, and recording of environmental conditions in and around the vehicle. Further testing of the RMS was conducted by removing and replacing a payload in the cargo bay. Military payload in the cargo bay tested IR and UV sensors and space sextant for future surveillance missions.
11 to 16 Nov 1982	STS-5 (Columbia)	Vance D. Brand (former naval aviator) Robert F. Overmyer, USMC	First operational mission of Space Shuttle. Crew deployed two communications satellites for successful transfer to geosynchronous orbit (SBS-3 and Anik C-3).
04 to 09 Apr 1983	STS-6 (Challenger)	Paul J. Weitz, USN	Maiden flight of the Challenger. Crew deployed Tracking and Data Relay Satellite (TDRS) for transfer to geosynchronous orbit. First EVA into the cargo bay; first use of a heads up display; first use of an Inertial Upper Stage (IUS) to boost TDRS to final orbit. Experiments included Getaway Specials (GAS).
18 to 24 Jun 1983	STS-7 (Challenger)	Robert L. Crippen, USN Frederick H. Hauck, USN	Crew deployed two communications satellites for transfer to geosynchronous orbit (Telesat-F & Palapa-B1). First pictures of Orbiter in orbit by still movie, and TV cameras mounted on deployed SPAS pallet.

30 Aug to 05 Sep 1983	STS-8 (Challenger)	Richard H. Truly, USN Daniel C. Brandenstein, USN Dale A. Gardner, USN	First night launch and landing. Crew deployed Indian National Satellite (Insat 1B). In-orbit test of the TDRSS. Extensive operations with the Payload Deployment and Retrieval System test article using the RMS.
28 Nov to 08 Dec 1983	STS-9 (Columbia)	John W. Young, USN	Maiden flight of the Spacelab that remained fixed in Columbia's cargo bay. The crew verified Spacelab's engineering performance by flying a variety of experiments in five broad scientific and technological disciplines.
03 to 11 Feb 1984	STS 41-B (Challenger)	Vance D. Brand, (former naval aviator) Robert L. Gibson, USN Bruce McCandless, USN	Crew deployed the first of two communications satellites from Challenger's cargo bay on first day in orbit, using the Payload Assist Module (PAM) to transfer to geosynchronous orbit. Neither spacecraft achieved correct orbit because of defective PAMs. McCandless became first human satellite as he orbited alongside the Orbiter in a Manned Maneuvering Unit (see fig. 1-11). At the end of the mission, Challenger achieved first Orbiter landing at Kennedy Space Center.
06 to 13 Apr 1984	STS 41-C (Challenger)	Robert L. Crippen, USN	Direct insertion into orbit allowed Challenger to achieve record altitude of 309 mi. On day 2, the crew deployed the Long Duration Exposure Facility (LDEF), which exposed various materials to the space environment for later retrieval and analysis on Earth. On day 3 the Orbiter rendezvoused with the Solar Maximum Mission Satellite (SMM), and after several attempts, captured and brought it into the cargo bay, where repairs were made. SMM was then deployed to continue with its mission.
30 Aug to 05 Sep 1984	STS 41-D (Discovery)	Michael L. Coats, USN	Crew deployed communications satellite Leasat 1 for transfer to geosynchronous orbit on day 1. The OAST-1 experimental solar array was extended and retracted successfully, and a commercial electrophoresis experiment designed to separate biological material for use in new drugs was tested.
05 to 13 Oct 1984	STS 41-G (Challenger)	Robert L. Crippen, USN Jon A. McBride, USN David C. Leestma, USN Kathryn Sullivan, USNR	The Earth Radiation Budget Satellite (ERBS) was deployed successfully first flight day. Another primary payload was the Shuttle Radar Laboratory, which was designed for map-making and interpretation of geological features. During a 3-hr EVA, Leestma and Kathy Sullivan tested refueling techniques for restoring spent satellites to useful life.
08 to 15 Nov 1984	STS 51-A (Discovery)	Frederick H. Hauck, USN David M. Walker, USN	Successfully deployed two communications satellites (Telsat-H &

		Dale A. Gardner, USN	Least 2) for transfer to geosynchronous orbit. Rendezvoused with two other satellites and recovered them in the cargo bay for return to Earth (Palapa B2 & Westar 6).
24 to 27 Jan 1985	STS 51-C (Discovery)	Thomas K. Mattingly, USN James A. Buchli, USMC	First dedicated military mission. Crew deployed a national security satellite some 16 hours into the mission. Landing took place at Kennedy Space Center.
12 to 19 Apr 1985	STS 51-D (Discovery)	Donald E. Williams, USN S. David Griggs, USNR (1 <sup>st</sup> commanding officer of Naval Space Command Reserve Unit)	Crew successfully deployed two communications satellites (Telesat-1 & Leasat 3-shown in fig. 1-12). However, Leasat 3's apogee kick motor failed to ignite as planned. Griggs and Jeff Hoffman performed first unscheduled EVA to attach a makeshift tool to end of RMS to trip power switch. Switch was tripped but efforts were in vain.
29 Apr to 06 May 1985	STS 51-B (Challenger)	Robert F. Overmyer, USMC	Considered to be the first operational launch of Spacelab after Spacelab 1 check-out mission. Crew also deployed a "getaway special" sub satellite.
17 to 24 June 1985	STS 51-G (Discovery)	Daniel C. Brandenstein, USN John O. Creighton, USN	Successfully deployed 3 communications satellites on first 3 days of the flight (Morelos-1A, Arabsat-1A, & Telstar3-D). Also deployed and recovered by the RMS was Spartan 1, which uses X-ray sensors to search for hot gas clouds in galaxy clusters.
03 to 07 Oct 1985	STS 51-J (Atlantis)	David C. Hilmer, USMC	Maiden flight of Orbiter Atlantis. A dedicated DOD mission that achieved highest altitude for an orbiter to date. Deployed two DSCS-3 military communications satellites using a single IUS booster.
30 Oct to 06 Nov 1985	STS 61-A (Challenger)	James F. Buchli, USMC	Largest Orbiter crew carried aloft. Spacelab mission with experiments managed by W Germany and controlled from the German Operations Control Center. Mission also launched the GLOMR message relay satellite.
26 Nov to 03 Dec 1985	STS 61-B (Atlantis)	Bryan D. O'Connor, USMC	Successfully deployed three communications satellites on first 3 days of the flight (Morelos-2, Aussat 2, & RCA Satcom K-2). Astronauts erected and dismantled a tower (Experimental Assembly of Structures in EVA-Ease) & a pyramid (Assembly Concept for Construction of Erectable Space Structures-ACCESS) during two EVAs.
12 to 18 Jan 1986	STS 61-C (Columbia)	Robert L. Gibson, USN Charles F. Bolden, USMC	Communications satellite RCA Satcom K1 deployed with PAM-D2; subsequently positioned in geosynchronous orbit. Astronauts conducted materials science experience, tested SDI related surveillance

			equipment, and documented protein crystal growth.
28 Jan 1986	STS 51-L (Challenger)	Michael J. Smith, USN	Challenger exploded shortly after launch from Kennedy Space Center, killing all seven crewmembers. (See Note 1)
29 Sep to 03 Oct 1988	STS-26 (Discovery)	Frederick H. Hauck, USN David C. Hilmers, USMC John M. Lounge, Civ (USNA grad)	Return to flight. A Tracking and Data Relay Satellite (TDRS) was successfully deployed, and 11 scheduled middeck scientific and technological experiments were carried out. Operated from the middeck was environmental experiment, Oasis, to measure TDRS vibration, strain, acoustics, and temperature during Orbiter ascent. Discovery landed at Edwards AFB upon return, as shown in Figure 1-13.
02 to 06 Dec 1988	STS-27 (Atlantis)	Robert L. Gibson, USN William M. Shepherd, USN	Classified DOD military payload deployed during 5 <sup>th</sup> orbit was the Lacrosse radar imaging reconnaissance satellite. Crew performed observations related to ground and ocean surveillance.
13 to 18 Mar 1989	STS-29 (Discovery)	Michael L. Coats, USN James F. Buchli, USMC Robert C. Springer, USMC	Crew deployed TDRS relay satellite, which was later boosted to geosynchronous orbit by IUS. They also tested the Space Station heat pipe advanced radiator, performed protein crystal growth experiments, and two student experiments.
04 to 08 May 1989	STS-30 (Atlantis)	David M. Walker, USN	Crew deployed Venus probe Magellan and attached two-stage IUS booster from cargo bay about 6 hrs into mission. Secondary experiments included fluid research in general liquid chemistry and study of electrical storms in Earth's atmosphere.
08 to 13 Aug 1989	STS-28 (Columbia)	Richard N. Richards, USN David C. Leestma, USN	Dedicated DOD mission. Crew deployed upgraded reconnaissance satellite some 7 hrs into the mission. Secondary mission was a science payload related to SDI plus 7 other experiments.
18 to 23 Oct 1989	STS-34 (Atlantis)	Donald E. Williams, USN Michael J. McCulley, USN	Crew deployed Jupiter probe Galileo and attached two-stage IUS booster from cargo bay about 6 hrs into mission.
22 to 27 Nov 1989	STS-33 (Discovery)	Manley L. Carter, Jr., USN	Dedicated military mission. Crew deployed a national security satellite some 16 hours into the mission.
09 to 20 Jan 1990	STS-32 (Columbia)	Daniel C. Brandenstein, USN James D. Wetherbee, USN	Navy Communications satellite Syncom IV deployed; subsequently positioned in geosynchronous orbit. Crew retrieved the LDEF after nearly 6 years in space and returned it to Earth for analysis. Longest shuttle flight to date (11 days).
28 Feb to 04 Mar 1990	STS-36 (Atlantis)	John O. Creighton, USN David C. Hilmers, USMC	Dedicated military mission. Crew deployed a national security satellite.

		Pierre J. Thuot, USN	
24 to 29 Apr 1990	STS-31 (Discovery)	Charles F. Bolden, USMC Bruce McCandless, USN Kathryn N. Sullivan, USNR	Crew deployed the Hubble Space Telescope (HST) from the cargo bay to begin that spacecraft's 15-year mission. HST is designed to be refurbished on orbit by Shuttle crews in the future.
06 to 10 Oct 1990	STS-41 (Discovery)	Richard N. Richards, USN Robert D. Cabana, USMC William M. Shepherd, USN	Crew deployed scientific probe Ulysses and attached two-state IUS booster from cargo bay about 6 hrs into mission.
15 to 20 Nov 1990	STS-38 (Atlantis)	Frank L. Culbertson, USN Robert C. Springer, USMC	Dedicated military mission. Crew deployed a national security satellite.
02 to 10 Dec 1990	STS-35 (Columbia)	John M. Lounge, Civ (USNA grad)	Crew used Astro-01 palletized astronomical laboratory to make observations from the Orbiter.
05 to 11 Apr 1991	STS-37 (Atlantis)	Kenneth D. Cameron, USMC	The Gamma Ray Observatory (GRO) was successfully deployed. GRO will transmit data on the source and power of gamma rays from within the Milky Way, and outside the galaxy.
28 Apr to 06 May 1991	STS-39 (Discovery)	Michael L. Coats, USN	Deployed and retrieved the Infrared Background Survey Satellite (IBSS). Conducted experiments to evaluate infrared and ultraviolet sensor technologies for the DOD.
05 to 14 Jun 1991	STS-40 (Columbia)	Bryan D. O'Connor, USMC	First Spacelab life sciences mission. Investigated the effects of micro gravity on human physiology for long duration space missions.
02 to 11 Aug 1991	STS-43 (Atlantis)	Michael A. Baker, USN	Crew deployed TDRS relay satellite, which was later boosted to geosynchronous orbit by IUS.
02 to 18 Sep 1991	STS-48 (Discovery)	John O. Creighton, USN Kenneth S. Reightler, USN James F. Buchli, USMC	Crew deployed NASA's Upper Atmosphere Research Satellite (UARS) on a multi-year mission to study the Earth's atmosphere.
24 Nov to 01 Dec 1991	STS-44 (Atlantis)	Mario Runco, Jr., USN Story Musgrave (former USMC)	DOD crew deployed improved Defense Support Program (DSP) missile warning satellite; later boosted into geosynchronous orbit; conducted numerous Military Man-in-Space experiments.
22 to 30 Jan 1992	STS-42 (Discovery)	Steven S. Oswald, USNR (4 <sup>th</sup> CO of NR NAVSPACECOM) William F. Readdy, USNR (5 <sup>th</sup> CO of NR NAVSPACECOM) David C. Hilmers, USMC Norman E. Thaggard (former USMC)	Multi-national crew operated the first international Microgravity Laboratory in the Spacelab module in Discovery's payload bay. This Space Station precursor mission carried experiments from 16 countries.
24 Mar to 02 Apr 1992	STS-45 (Atlantis)	Charles F. Bolden, USMC David C. Leestma, USN Kathryn Sullivan, USNR	Crew operated the first NASA Atmospheric Laboratory for Applications and Science to study the Earth's atmosphere and the Sun.
07 to 16 May 1992	STS-49 (Endeavour)	Daniel C. Brandenstein, USN	Crew succeeded in dramatic EVA rescue

		Pierre J. Thuott, USN	of the stranded INTELSAT communications satellite and conducted EVA experiments in preparation for Space Station assembly. Numerous world EVA records were established and the maiden voyage of ENDEAVOUR concluded with the first use of a drag chute during landing.
25 Jun to 09 Jul 1992	STS-50 (Columbia)	Richard N. Richards, USN Kenneth D. Bowersox, USN	Following COLUMBIA's extensive outfitting as the first Extended Duration Orbiter (EDO), the crew set a new Shuttle mission duration record of almost 14 days while operating the first U.S. Microgravity Lab (USML) in the Spacelab module.
31 Jul to 08 Aug 1992	STS-46 (Atlantis)	Andrew M. Allen, USMC	Crew deployed the first flight of the European Retrieval Carrier (EURECA) and the joint NASA -Italian Space Agency (ASI) Tethered Satellite System (TSS).
12 to 20 Sep 1992	STS-47 (Endeavour)	Robert L. Gibson, USN	50 <sup>th</sup> flight of the Space Shuttle Era. Endeavour carried the first Japanese Spacelab experiment compliment as a pathfinder for the Japanese experiment module on Space Station FREEDOM.
22 Oct to 01 Nov 1992	STS-52 (Columbia)	James D. Weatherbee, USN William M. Sheppard, USN Michael A. Baker, USN	Crew deployed the Laser Geodynamics Satellite (LAGEOS), and operated the first United States Microgravity Payload (USMP), and a set of Canadian Experiments (CANEX-2).
02 to 09 Dec 1992	STS-53 (Discovery)	David M. Walker, USN	On the last dedicated DOD shuttle flight, the crew deployed a classified satellite and conducted several Military Man-in-Space experiments.
13 to 19 Jan 1993	STS-54 (Endeavour)	Mario Runco, USN	Crew deployed the sixth IUS/TDRS. LCDR Runco completed a 4 hr, 28 minute EVA to evaluate techniques for building Space Station Freedom.
12 to 23 Sep 1993	STS-51 (Discovery)	Frank Culbertson, Jr., USN Daniel W. Bursch, USN	Deployed Advanced Communications Satellite. First night landing at Kennedy Space Center.
02 to 23 Dec 1993	STS-61 (Endeavour)	Kenneth Bowersox, USN	First Hubble servicing mission.
10 Sep to 11 Oct 1994	STS-68 (Endeavour)	Michael Baker, USN Daniel Bursch, USN	Deployed Space Radar Lab-2
03 to 11 Feb 1995	STS-63 (Discovery)	James Weatherbee, USN	Rendezvoused with <i>Mir</i> with second Russian aboard U.S. Spacecraft.
02 to 18 Mar 1995	STS-67 (Endeavour)	Wendy Lawrence, USN	Deployed Astro-2 UV telescope array.
20 Oct to 05 Nov 1995	STS-73 (Columbia)	Kenneth Bowersox, USN Kent Rominger, USN	Deployed U.S. Microgravity Lab-2 Spacelab.

		Michael Lopez-Alegria, USN	
11 to 20 Jan 1996	STS-72 (Endeavour)	Brent Jett, USN Winston Scott, USN	Retrieved Japan's Space Flyer Unit and deployed Spartan OAST-Flyer.
19 to 29 May 1996	STS-77 (Endeavour)	Daniel Bursch, USN Mario Runco, USN	Deployed Spacelab-4 satellite.
20 Jun to 07 Jul 1996	STS-78 (Columbia)	Charles Brady, USN	Deployed Life & Microgravity Science Spacelab satellite.
19 Nov to 07 Dec 1996	STS-80 (Columbia)	Kent Rominger, USN	Deployed and retrieved Wake Shield Facility 3 satellite.
12 to 22 Jan 1997	STS-81 (Atlantis)	Michael Baker, USN Brent Jett, USN	Docked with, delivered supplies to, and crew exchange with <i>Mir</i> .
11 to 21 Feb 1997	STS-82 (Discovery)	Kenneth Bowersox, USN	2 <sup>nd</sup> servicing mission to Hubble.
04 to 08 Apr 1997	STS-83 (Columbia)	Susan Still, USN	Deployed Microgravity Science Lab 1. Mission curtailed because of fuel cell problems.
01 to 17 Jul 1997	STS-94 (Columbia)	Susan Still, USN	Re-flight of STS-83. Same mission.
25 Sep to 06 Oct 1997	STS-86 (Atlantis)	James Wetherbee, USN	7 <sup>th</sup> <i>Mir</i> docking, crew exchange.
19 Nov to 05 Dec 1997	ST-87 (Columbia)	Winston Scott, USN	Deployed U.S. Microgravity Payload #4.
22 to 31 Jan 1998	STS-89 (Endeavour)	Joe Edwards, USN	8 <sup>th</sup> <i>Mir</i> docking, crew exchange.
17 Apr to 03 May 1998	STS-90 (Columbia)	Scott Altman, USN	Deployed Neurolab satellite.

Note 1: Challenger STS 51-L crewmembers: Francis R. Scobee, Michael J. Smith, Judith A. Resnik, Ellison S. Onizuka, Ronald E. McNair, Gregory B. Jarvis, and Sharon Christa McAuliffe.

Note 2: On October 29, 1998, Senator John Glenn (former-USMC) returned to space aboard Discovery on STS-95



Figure .1-11. First human satellite.



Figure 1-12. Communication satellites.

### **Military Manned Space**

Parallel efforts were underway during the early '60s to use manned space flight to augment the use of unmanned spacecraft. Two major programs were the X-20 Dynasoar and the Manned Orbiting Laboratory (MOL).

Started in 1960 while the *Mercury* program was in final preparations, the *Dynasoar* was an entirely U.S. Air Force project intended to be the logical follow-on to the X-15 rocket plane. It was a single-seat, winged spacecraft constructed of titanium and columbium, intended to be launched atop a Titan III missile and flown to a conventional landing. The program was planned for first flight in 1966 with an initial operating capability three years later. In 1963, *Dynasoar* was canceled in favor of the NASA Gemini-manned capsule approach to putting humans in orbit.

The Manned Orbiting Laboratory design concept was begun in 1963 and approved in 1965 during the Johnson Administration as a low-cost approach to providing a continuous, military manned presence in orbit. McDonnell Aircraft Company was to modify a Titan upper stage into an orbiting laboratory. The program intended to use the existing *Gemini* capsule to fly the crew to the MOL. Its initial operating capability was originally planned for 1968. Budgetary problems and program slippages led to the program's cancellation in 1969. Fourteen military astronauts were already chosen for the



program and seven, among them CDR Richard Truly, CDR Robert Crippen, and LCOL Robert Overmeyer, USMC, were transferred to NASA for future missions as the space agency's seventh astronaut group.

The Military Manned Spaceflight Engineer program was sponsored by the Air Force to support the planned DoD missions on the Space Shuttle manifest. Spaceflight engineers were selected from all three services to fly as Payload Specialists on DoD flights, but only two from this program flew before it was canceled. DoD missions will continue to be flown by NASA crews as required to support national defense missions.

## **SUMMARY**

This nation's successes in space are not merely the product of a few highly trained astronauts and space professionals. Space operations would not have been possible without the many thousands of dedicated sailors, scientists, engineers, and Marines. Their contributions ranged from developing the spacesuits and recovery parachutes, to training the astronauts in centrifuges and water survival, as well as manning the many tracking and communications sites and recovery forces around the world for all of the manned space missions.

The U. S. Navy continues to emphasize space as a supporting element of its global mission, with organic control of space assets remaining high on the Navy's list of priorities. Innovative thinking from the fleet, emphasis on specialized aerospace and space systems education at the Naval Postgraduate School in Monterey, CA, coupled with the resources of the Naval Research Laboratories continue to lead this country's efforts in pioneering and exploiting the space frontier.



Figure 1-13. Discovery landing.



## **CHAPTER 2**

# **U.S. SPACE ORGANIZATIONS**

### **INTRODUCTION**

There are several organizations responsible for DoD space operations. United States Space Command (USSPACECOM) is a Joint Command with three component organizations consisting of Air Force Space Command, Army Space Command and Naval Space Command. USSPACECOM provides space support for unified commanders worldwide. In addition, space organizations provide warning data for the North American Aerospace Defense Command (NORAD) mission and theater ballistic missile defense units. In this chapter we will review the roles and responsibilities of the various space organizations and how they contribute warfighter support in meeting the objectives of preserving peace and protecting U.S. national security.

A nation's space policy is extremely important, especially as it relates to space law and space doctrine. While policy provides goals and a framework for our space program, it is in turn shaped by national interests and national security objectives. Policy provides the lead for building and meeting future U.S. requirements and subsequent national space strategies.

Consequently, our national space policy will be reviewed in this chapter. This will enable the reader to fully appreciate the degree to which the DoD has recognized the utility of space in accomplishing national security objectives and the extent to which it has embraced the space role given it by law and national policy.

### **NATIONAL SPACE POLICY**

The National Space Policy, approved by President Clinton on 19 September 1996, updates the 1989 Presidential Directive, and represents the first post-Cold War assessment of American space goals and activities. The policy commits the nation to a strong and stable program in space that addresses both U.S. civil and national security requirements, and will ensure America's role as the world's space leader.

The overall goals of the United States space program are to:

- Enhance knowledge of the Earth, the solar system and the universe through human and robotic exploration;
- Strengthen and maintain the national security of the United States;
- Enhance the economic competitiveness, and scientific and technical capabilities of the United States;

- Encourage state, local and private sector investment in, and use of, space technologies; and
- Promote international cooperation to further U.S. domestic, national security, and foreign policies.

The United States is committed to the exploration and use of space by all nations for peaceful purposes and for the benefit of all humanity. "Peaceful purposes" allows defense and intelligence-related activities in pursuit of national security and other goals. The United States rejects all claims to sovereignty by any nation over outer space or celestial bodies or any portion thereof, and rejects any limitations on the fundamental right of sovereign nations to acquire data from space. The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems is viewed as an infringement on sovereign rights.

The National Science and Technology Council (NSTC) is the principal forum for resolving issues related to a national space policy. As appropriate, the NSTC and National Security Council (NSC) will co-chair the policy processes.

National Space Policy specifically directs the national security space sector (composed primarily of the Secretary of Defense (SecDef) and the Director of Central Intelligence (DCI)), to conduct space activities necessary for national security by:

- Providing support for the United States' inherent right -of self-defense and our defense commitments to allies and friends;
- Deterring, warning, and if necessary, defending against enemy space attack;
- Assuring that hostile forces cannot prevent our own use of space;
- Countering, if necessary, space systems and services used for hostile purposes;
- Enhancing operations of U.S. and allied forces;
- Ensuring our ability to conduct military and intelligence space-related activities;
- Satisfying military and intelligence requirements during peace and crises as well as through all levels of conflict; and
- Supporting the activities of national policy makers, the intelligence community, the National Command Authorities, combatant commanders and military services, other federal officials, and continuity of government operations.

Further, the policy directs a closer coordination between the Department of Defense (DoD) and intelligence community activities related to space policy.

Within the national security sector, specific DoD guidelines include the directive to maintain the capability to execute the mission areas of space support, force enhancement, space control and force application.

Space Control activities are necessary to ensure freedom of action in space, thus supporting all space activities, and if directed, DoD space control capabilities will be employed to deny such freedom of action to adversaries. These defense capabilities may be enhanced by diplomatic, legal or military measures to preclude an adversary's hostile use of space systems and services. The U.S. will maintain and modernize space surveillance and associated battle management command, control, communications, computers, and intelligence to effectively detect, track, categorize, monitor, and characterize threats to U.S. and friendly space systems and contribute to the protection of U.S. military activities.

DoD will continue to serve as the launch agent for both the defense and intelligence sectors, and maintain the capability to evolve and support those space transportation systems, infrastructure, and support activities necessary to meet national security objectives. DoD will be the lead agency for improvement and evolution of the current expendable launch vehicle fleet, to include technology development.

DoD will pursue integrated satellite control and continue to enhance the robustness of its satellite control capability, and where appropriate, foster the integration and interoperability of satellite control for all governmental space activities.

The SecDef, in concert with the DCI, and for the purposes of supporting operational military forces, may propose modifications or augmentations to intelligence space systems as necessary. The DoD may develop and operate space systems to support military operations in the event that intelligence space systems cannot provide the necessary intelligence support.

The United States will pursue a ballistic missile defense program to provide for: future enhanced theater missile defense; a national missile defense deployment readiness program as a hedge against the emergence of a long-range ballistic missile threat to the United States; and an advanced technology program to provide options for improvements to planned and deployed defenses.

Specific guidance for the intelligence portion of the national security sector includes the timely provision of information and data to support: foreign, defense and economic policies; military operations; diplomatic activities; indications and warning; crises management; and treaty verification, and to conduct research and development activities related -to these functions.

The DCI shall continue to develop and apply advance technologies that respond to changes in the threat environment and support national intelligence priorities. The DCI shall work closely with the SecDef to improve the intelligence space sector's ability to support military operations worldwide.

The lead agency for research and development in civil space activities is the National Aeronautics and Space Administration (NASA). NASA, in coordination with other departments and agencies, will focus research and development efforts in space science to enhance knowledge of the solar system, the universe, and fundamental natural and physical sciences; Earth observation to better understand global change and the effect of natural and human influences on the environment; human space flight to conduct scientific, commercial and exploration activities; and space technologies and applications in support of U.S. Government needs and our economic competitiveness. Activities include: development and operation of the International Space Station; development of next-generation reusable launch systems; research activities and programs to support a robotic presence on the surface of Mars; and the development of innovative space technologies, and smaller and more capable spacecraft.

Also within the civil space sector, the Department of Commerce (DOC), through the National Oceanographic and Atmospheric Administration (NOAA), has the lead responsibility for managing Federal space-based civil operational Earth-observations necessary to meet civil requirements.

The Department of the Interior (DoI), through the U.S. Geological Survey (USGS) will maintain a national archives of land remote sensing data and other surface data as appropriate, making the data available to U.S. Government and other users.

The fundamental goal of the U.S. commercial space sector is to support and enhance U.S. economic competitiveness in space activities while protecting U.S. national security and foreign policy interests. Expanding U.S. commercial space activities will generate economic benefits for the Nation and provide the U.S. Government with an increasing range of space goods and services. U.S. Government agencies shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with commercial applications that preclude or deter commercial space activities except for reasons of national security.

The United States will pursue its commercial space objectives without direct Federal subsidies. Commercial Sector space activities shall be supervised or regulated only to the extent required by law, national security, international obligations and public safety.

## **MILITARY SPACE ORGANIZATIONS**

The DoD Space Policy implements the National Security Space Policy. The primary DoD goal in space is to provide operational capabilities to ensure that the United States can meet national security objectives. Support of these objectives involves using space as a medium from which to conduct and support military missions.

Each of the armed services is assigned responsibilities to organize, train, equip and provide forces for either land, maritime or air warfare. Over the past four decades, the services have relied more and more on space assets to conduct or support their assigned missions. During the 1980s, each service consolidated space operations under its own space command. In 1985, the JCS established the USSPACECOM as a unified command to, control U.S. military space assets and to coordinate across service boundaries. Once established, USSPACECOM was assigned operational command (OPCOM) of the service space commands, now considered component commands. The DoD organization for space operations is depicted in Figure 2-1.

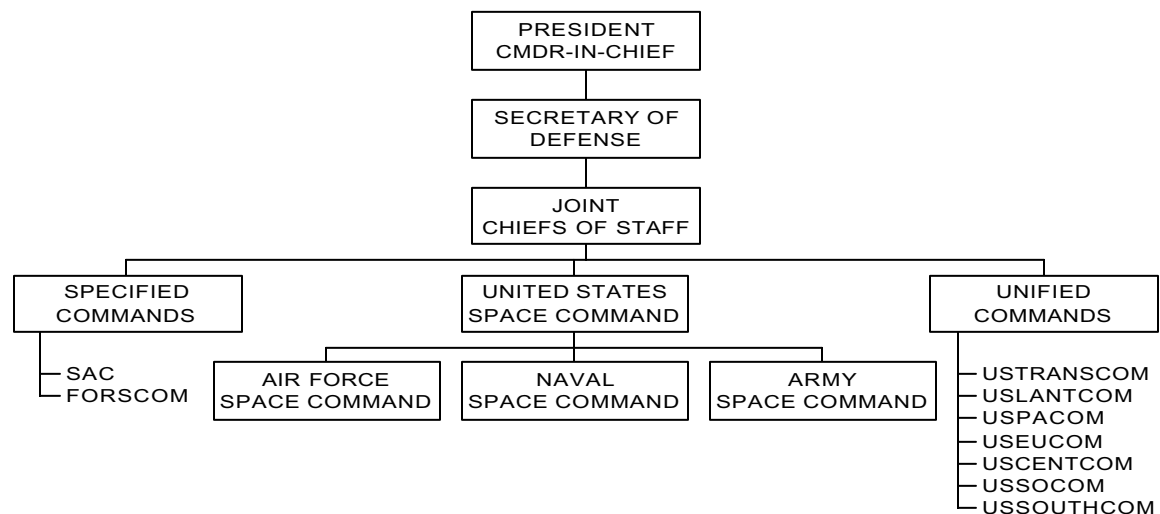


Figure 2-1. Military space organizations—operational chain of command.

## Department of the Air Force

In addition to the shared responsibilities to provide forces for the strategic defense of the U.S. and coordination with the other services for space operations, the Department of the Air Force is specifically assigned the missions of acquiring and operating launch vehicles; developing, producing, and deploying space systems for warning and surveillance of nuclear attack; and providing orbital operations support for DoD missions. The Air Force performs these missions for the benefit of all the services. The Air Force also uses space systems for communications, navigation, surveillance, and environmental monitoring to accomplish its own primary mission of maintaining air supremacy in support of national objectives.

Historically, the Air Force has been the principal provider of space systems for DoD, and remains uniquely postured for that role. The Air Force offers a career path in space systems. Career paths are available in several space-related operations, engineering, and staff fields for both officer and enlisted personnel. With these career space personnel, the Air Force has established an infrastructure representing approximately 90 percent of DoD's space experienced personnel and 80 percent of the DoD space budget.

Current Air Force initiatives include developing increased launch capacity to ensure unimpeded access to space, anti-satellite command and control capabilities to ensure that we can deny an adversary use of his space systems, a space-based wide area surveillance system to increase surveillance capability for defense of the United States, and a survivable satellite command and control system to provide uninterrupted space operations.

## **UNITED STATES SPACE COMMAND**

On September 23, 1985, the United States Space Command (USSPACECOM) was activated to consolidate all military space efforts under the direction of one commander-in-chief (CINC) directly responsible to the President through the Secretary of Defense and Chairman, Joint Chiefs of Staff.

USSPACECOM is a unified command of the DoD and is headquartered at Peterson Air Force Base, Colorado. . Personnel from the Army, Marine Corps, Navy and Air Force staff the command. USSPACECOM oversees three service component commands: Army Space and Missile Defense Command, Naval Space Command, and Air Force Space Command.

USSPACECOM provides joint employment of military forces and operational support to other unified combatant commands. The command performs these functions through four primary missions: space support, force enhancement, space control, and force application.

Space Support: Space support operations include launch and on-orbit satellite command and control operations. Space support is provided by Army, Naval and Air Force Space Commands. The U.S. has two primary launch sites; located at Cape Canaveral Air Force Station (CCAFS), FL, and Vandenberg AFB, CA.

Air Force Space Command (AFSPC) operates the launch wings at each base and is engaged in a major program to restore and modernize launch facilities. AFSPC launches warning, navigation and communications satellites from Cape Canaveral into low or synchronous orbits. Once a satellite is in orbit, a worldwide network of ground stations controls it. Scheduling is done by AFSPC at Shriever AFB, CO, and Onizuka Air Station (AS), CA. NAVSPACECOM controls the Fleet Satellite (FLT SAT) and UHF Follow-On (UFO) communications satellites. The U.S. Army Space and Missile Defense Command (SMDC) operates the Defense Satellite Communications Systems' (DSCS) payloads supporting worldwide combat needs.

Force Enhancement: Space systems provide direct support to land, sea, and air forces. To meet this need, USSPACECOM has control-of a fleet of satellites that provide ballistic missile warning, communications, weather and navigation, and positioning support. U.S. forces also employ commercial communications satellites, civil weather satellites, and civil multi-spectral imagery satellites.



Defense Support Program (DSP) satellites provide warning data on ballistic missile launches. FLTSAT, DSCS, UFO and Air Force Satellite Communications System (AFSATCOM) provide satellite communications support. The Defense Meteorological Satellite Program (DMSP) and civil-meteorological satellites provide weather data. The Global Positioning System (GPS) satellites provide navigation and positioning. U.S. LANDSAT, IKONOS and French SPOT satellites provide multi-spectral imagery on the commercial market.

During Operations "Desert Shield" and "Desert- Storm," space assets met the needs of U.S. land, sea and air forces; frequently providing capabilities and support not envisioned when the systems were on the drawing boards. For example, the alerting system that warned of SCUD attacks was based on warning provided by DSP satellites, originally designed to warn of intercontinental ballistic missile (ICBM) attack.

Ground forces that initially deployed to Desert Shield had access to the United States' most effective means of navigation, the GPS. Thousands of commercial GPS receivers were purchased to meet the demand of GPS navigation and positioning data. Deployed forces received weather data broadcast by satellites and used maps produced from space-borne platforms. Satellite communication was the backbone for long haul and intra-theater connectivity for Desert Shield and Desert Storm, with over 90% of communications into and out of the theater carried over communication satellites.

Space Control: Space control is essential to the success of future United States land/sea/air military operations. Assured access to, and unimpeded operation in space, and the denial to an enemy of the same, are the key tenets of space control operations.

The three pillars of space control are surveillance, protection, and negation. The USSPACECOM worldwide Space Surveillance Network (SSN) is tasked to detect, track, identify, and catalog all man-made space objects to ensure space operations are conducted without interference. The USSPACECOM Space Control Center (SCC) in Cheyenne Mountain provides warning to United States space system operators to protect their satellites from potentially hostile situations or dangerous natural events.

Disrupting, degrading, denying or destroying space-based support to hostile military forces are the basic principles of negation. The United States has no operational anti-satellite (ASAT) weapon system. However, research and development into ASAT technology is continuing. An operational ASAT would deter threats to U.S. space systems, enabling U.S. to negate hostile space-related forces and ensuring the right of self-defense.

Force Application: Force application will be performed through the planned acquisition of ballistic missile defense systems.

The Missile Defense Act of 1991, as amended by Congressional language in 1992, directs the DoD to provide protection of the U.S., forward deployed U.S. forces, and allies from limited ballistic missile strikes.

Ballistic missile defense systems are divided into theater defense systems to counter short, medium and intermediate range ballistic missiles, and U.S. defense systems to counter ICBMs.

USSPACECOM will provide space-based ballistic missile support (warning, surveillance, cueing, etc.) to theater commanders for theater missile defense (TMD) and to the North American Aerospace Defense Command (NORAD) for the protection of the North American Continent against ICBM threats.

### **Space Surveillance**

Space surveillance is a critical part of USSPACECOM's mission. Involves detecting, tracking, cataloging and identifying man-made objects orbiting Earth, e.g. active/inactive satellites, spent rocket bodies or fragmentation. Space surveillance accomplishes the following:

- Predicts when and where a decaying satellite will re-enter the Earth's atmosphere;
- Charts the present position of space objects and plots anticipated orbital paths;
- Detects new man-made objects in space;
- Produces a running catalog of man-made space objects;
- Determines which country owns a re-entering space object; and
- Informs NASA if objects may interfere with the Space Shuttle.

The command accomplishes these tasks through its worldwide network of Space Surveillance Network (SSN) radar and optical sensors.

### **Space Surveillance Network (SSN)**

The SSN has been tracking space objects since 1957 when the USSR opened the space age with the launch of SPUTNIK I. Since then, the SSN has tracked and cataloged more than 23,000 space objects. The SSN currently tracks about 10,000 objects. The space objects now orbiting Earth range from satellites weighing several tons to pieces of spent rocket bodies weighing only 10 pounds. About 7% of the space objects are operational satellites; the rest are debris. The SSN tracks space objects which are 10 centimeters in diameter (baseball size) or larger. The SSN uses a "predictive" technique to track space objects; i.e., it spot-checks them rather than tracking them continually. This technique is used because of SSN limitations (number of sensor, geographic distribution, capability, and availability). The SSN consists of the types of sensors shown in Table 2-1.

<b>Table 2-1. Space Surveillance Network (SSN) Sensors</b>	
Mechanical Tracking Radar	Large dish antenna radar that are mechanically rotated in azimuth and raised in elevation to locate and track an object.
Detection Fan Radar	Older technology. Area search radar systems that monitor large sections of space. Stationary objects are detected as they pass through the search area.
Phased Array Radar	Newer technology. Area search radar can simultaneously monitor sections of space and track multiple objects as they orbit overhead. They have no moving parts to limit the speed of the radar scan; the radar energy is steered electronically.
Ground-Based Electro-Optical Deep Space Surveillance System (GEODSS)	Consists of three telescope sensors linked to video cameras. The video cameras feed their space pictures into a nearby computer which drives a display scope. The image is transposed into electrical impulses and recorded on magnetic tape—the same process used by video cameras. The image can be recorded and analyzed in real-time.

Combined, these types of sensors make 30,000 to 50,000 satellite observations each day. This enormous amount of data comes from SSN sites such as NAVSPACECOM, Maui, HI, Eglin AFB, FL, Thule, Greenland, and Diego Garcia, in the Indian Ocean. The data is transmitted to USSPACECOM's SCC via satellite, ground wire, microwave and telephone.

The SCC in Cheyenne Mountain is the terminus for the SSN's abundant and steady flow of information. The SCC houses large, powerful computers to process SSN information and accomplish the space surveillance missions.

NAVSPACECOM provides the site and processing capability for the Alternate SCC (ASCC) located at Naval Space Command, Dahlgren, VA. The ASCC would take over all operations in the event the SCC could not function. This capability is exercised weekly.

### **Air Force Space Command**

AFSPC is the Air Force component of USSPACECOM. The mission of AFSPC is to defend the United States through the control and exploitation of space. As such, the command is also responsible for organizing, training, equipping, and administering Air Force units in support of USSPACECOM's missions.

Air Force Space Command (AFSPC) is headquartered at Peterson Air Force Base in Colorado Springs, Colorado. The command was established in 1982 as an Air Force major command to bring space systems operation and planning on a par with other Air Force missions, such as tactical and strategic air supremacy. As a major-command, AFSPC organizes, trains, equips, sustains and operates assigned Air Force space, surveillance and missile warning systems. Specifically, the command:

- Operates military space systems - weather, communications, navigational and missile warning satellites;
- Operates ground-based radar and missile warning satellites to provide ballistic missile warning for North America;
- Operates the national launch centers and ranges to provide military, civil and commercial access to space;
- Operates worldwide surveillance radar to provide continuous information on the location of satellites and space debris in orbit;
- Operates the nation's intercontinental ballistic missile (ICBM) force.

AFSPC operates a host of different organizations to accomplish these objectives. These subordinate units are located around the world, operating from remote sites, stations, and bases. AFSPC personnel and units are organized into several wings.

**14<sup>th</sup> Air Force.** The 14<sup>th</sup> Air Force located at Vandenberg AFB, California plans and executes operations for space support, force enhancement and space control. It also serves as the operational component of AFSPACECOM by providing the day-to-day operators and managers of AFSPC's space forces. 14<sup>th</sup> Air Force is also responsible for AFSPC's operational planning and employment in wartime and during major worldwide exercises and contingencies. The 14<sup>th</sup> Air Force consists of subordinate units as discussed in the following paragraphs.

**21<sup>st</sup> Space Wing.** The 21st Space Wing is located at Peterson AFB, Colorado. Operates a network of dedicated missile warning sensors. These sensors provide Integrated Tactical Warning and Attack Assessment (ITW/AA) of sea and land-launched ballistic missile attacks against the continental United States and Canada. Resources include the Defense Support Program (DSP); a space based early warning system, phased-array radar and mechanical radar. The Wing provides day-to-day management, training and evaluation for the personnel at the missile warning, intelligence and communications units assigned to it. Included in this worldwide network of sensors are the PAVE PAWS SLBM warning system radar at Cape Cod AFS, Massachusetts and Beale AFB, California. Ballistic Missile Early Warning Systems (BMEWS) are located at Thule AB, Greenland, Clear AFS, Alaska and Fylingdale's Moor in the United Kingdom (U.K.). DSP ground stations are located in Colorado, Europe and Australia.

**30<sup>th</sup> Space Wing.** The 30<sup>th</sup> Space Wing is located at Vandenberg AFB, California and operates the Western Test Range. The Wing is responsible for launching and tracking expendable space boosters and conducting ICBM test launches from the West Coast of the U.S. The Delta II, Titan II and IV and a variety of other expendable boosters used for placing satellites into a variety of orbits, to include near-polar, are currently launched from the range.

**45<sup>th</sup> Space Wing.** The 45<sup>th</sup> Space Wing is located at Patrick AFB, Florida. It provides space launch and tracking facilities, safety procedures and test data to a wide variety of users. The Wing launches a variety of expendable vehicles to include the Delta II, Atlas II and Titan IV. It also provides support to the Space Shuttle program, operates Cape Canaveral AFS, and the Eastern Test Range. Additional responsibilities include launch operation and management of DoD space programs, and launch and tracking facilities for NASA, foreign governments, the European Space Agency and commercial customers.

**50<sup>th</sup> Space Wing.** The 50<sup>th</sup> Space Wing, located at Shriever AFB, Colorado, provides command and control of operational DoD spacecraft and management for the worldwide Air Force Satellite Control Network (AFSCN). The AFSCN is a network of eight satellite tracking stations linked by sophisticated communications equipment. The eight Remote Tracking Stations (RTS's) are: Vandenberg RTS, CA; Hawaii RTS, HI; Colorado RTS, CO; New Hampshire RTS, NH; Thule RTS, Greenland; Oakhanger RTS, UK; Guam Tracking Station, Guam; and the Diego Garcia Tracking Station, British Indian Ocean Territory. The AFSCN supports more than 110 DoD satellites by allowing satellite operators at Onizuka AS and Shriever AFB to communicate with and control the satellites for which they are responsible. Before an orbiting satellite passes over an RTS, the RTS equipment is configured for the specific satellite, pointed toward the satellite, and tested to ensure system readiness. Actual pass support begins with the acquisition of a satellite signal. Typical pass sequence activities include transmitter turn-on, health check, mission data readout, automatic sequence programming, satellite reconfiguration, and transmitter turn off. Recorded data is analyzed after the satellite passes. Typical satellite passes, including preparation, average 30 minutes to an hour depending on the satellites' orbit and the functions being performed. Low-Earth orbiting satellites are in view of the tracking stations for 15 minutes or less.

The 750<sup>th</sup> Space Group (750 SG) is a component of the 50th Space Wing and is located at Onizuka AFS, California. This organization is responsible for operations, maintenance and logistics support for the common user resources of the AFSCN. The Group monitors, maintains and updates the status of the AFSCN resources and provides the status of configurations and readiness of controlled resources to multiple users and command centers.

Two Resource Control Complexes belonging to the 750 SG are the 21<sup>st</sup> Satellite Operations Squadron (SOPS) at Onizuka AS and the 22<sup>nd</sup> SOPS at Shriever AFB. These organizations give the network dual node capability, insuring continual support for on-orbit satellites. They are responsible for scheduling the use of tracking stations for satellite operators at Onizuka AS and Shriever AFB. This capability enables them to make contact with the satellites through the tracking stations to accomplish the functions of command and control. Due to the Base Realignment and Closure List, AFSPC operations at Onizuka AS will be transferred to Shriever AFB. This move is expected to be completed by the year 2001.

The SOPS's under the 50<sup>th</sup> Space Wing at Shriever AFB perform tracking, telemetry and command functions for orbiting spacecraft. They are compatible with the SOPS located at

Onizuka AS and provide support to the Defense Meteorological satellite Program (DMSP), DSP, Navstar Global Positioning System (GPS), Defense Satellite Communications System (DSCS), NATO III, and the UHF Follow-On (UFO), MILSTAR and the technology for Autonomous Operational Survivability (TAOS) experimental satellite.

Also located at Shriever AFB are the GPS Master Control Station (GPS MCS) operated by the 2<sup>nd</sup> SOPS; the MILSTAR Master Control Center operated by the 4<sup>th</sup> SOPS; and the 50th Space Wing Command Post.

Co-located on Shriever AFB are the dual AFSCN terminals, the Colorado Tracking Station of the AFSCN and a GPS monitor station.

The 50<sup>th</sup> Space Wing subordinate units include the 1<sup>st</sup> through 7<sup>th</sup> SOPS:

**1<sup>st</sup> SOPS**, located at Shriever AFB provides routine, consolidated command and control support for three different systems: DSP, GPS, TAOS and other assigned Research and Development (R&D) spacecraft. The 1<sup>st</sup> SOPS operates and maintains 24-hour AFSCN command and control capability for the GPS and DSP systems. The squadron also operates and maintains R&D space systems that possess potential residual capabilities to support military operations. Early orbit operations performed by the 1<sup>st</sup> SOPS include satellite activation, initial checkout and transfer to mission orbit. The squadron plans and executes Tracking, Telemetry and Commanding (TT&C) functions for GPS and DSP satellites to maintain spacecraft state-of-health, sustain on-orbit operations and accomplish mission tasking. They also support satellite end of-life testing and conduct satellite disposal operations for GPS and DSP satellite. The 1<sup>st</sup> SOPS maintains DSP spacecraft positional data to 200 meters and distributes this data to a host of worldwide users. The squadron maintains the capacity to support at least six contacts for each DSP satellite per day. When required, the squadron can relocate operations within 48 hours to their back-up node at Onizuka AS to perform limited command and control to sustain on-orbit operations of assigned GPS and DSP satellites.

**2<sup>nd</sup> Sops**, located at Shriever AFB, provides command and control for the nominal GPS constellation of 24 satellites. GPS provides worldwide precision navigation service for U.S. and allied military forces as well as civilian users. The 2<sup>nd</sup> SOPS operates and maintains the GPS Master Control Station (MCS) and a dedicated network of monitor stations and ground antennas to control and monitor the satellite constellation. The monitor stations passively track the navigation signals on all the satellites. Information is processed at the MCS and is used to update the satellites' navigation messages. The MCS then sends updated navigation information to the GPS satellites through ground antennas. Ground Antennas are also used to transmit commands to satellites and to receive the satellites' state of health (SOH) telemetry.

**3<sup>rd</sup> SOPS** is also located at Shriever AFB and conducts both launch and on-orbit operations for military communications satellites for the DoD and Air Force Space Command. The 3<sup>rd</sup> SOPS conducts launch and on-orbit operations for DoD communications satellites,

which include the DSCS III, and MILSTAR. These satellites relay communications for the Defense Information Systems Agency (DISA). These organizations manage and maintain all primary peacetime and wartime communications links for the National Command Authority (NCA), theater commanders and all strategic and tactical forces worldwide. The 3<sup>rd</sup> SOPS also has the AF Satellite Communications (AFSATCOM) mission. AFSATCOM provides reliable, enduring, worldwide command and control communications to users based on a priority system outlined by the Joint Chiefs of Staff (JCS). Operational crews at the 3<sup>rd</sup> SOPS are responsible for providing telemetry analysis and tracking data for orbit determination and commanding of on-board subsystems for the DSCS III program. In addition, they are responsible for launch and early orbit operations for the Navy's UHF F/O spacecraft, a replacement for the Fleet Satellite (FLTSAT) Communications system. The 3<sup>rd</sup> SOPS also shares operational control of MILSTAP, a next generation communications satellite program, with the 4<sup>th</sup> SOPS. The 3<sup>rd</sup> SOPS was primarily responsible for the launch and emergency operations, but all operational control of MILSTAR has been turned over to the 4<sup>th</sup> SOPS. As the 3<sup>rd</sup> SOPS has been gaining control of new satellite systems, it has been working to focus its operations on these newest generation satellites. As a result, the operational mission for NATO III and DSCS II was transferred to 5<sup>th</sup> SOPS at Onizuka AS. Control of the aging FLTSAT constellation was surrendered to the Navy at Pt. Mugu, California, in June of 1996.

**4<sup>th</sup> SOPS** is located at Shriever AFB and is responsible for overall command and control of the MILSTAR satellite constellation. The 4<sup>th</sup> SOPS is responsible for ensuring that the MILSTAR system provides survivable, enduring, essential command and control communications through all levels of conflict for the NCA and warfighting Commanders-in-Chief worldwide. The 4<sup>th</sup> SOPS operates the MILSTAR system, executing communications management, satellite command and control, and ground segment maintenance for the MILSTAR constellation of satellites. MILSTAR is the most advanced military communications satellite system to date. The multi-satellite constellation links command authorities to high priority U.S. forces via MILSTAR terminals on aircraft, ships, submarines, trucks and ground sites through encrypted voice, data, teletype or facsimile communications.

**5<sup>th</sup> SOPS**, located at Onizuka AS, is responsible for planning and conducting launch and on-orbit support for a wide spectrum of DoD, allied and commercial space systems to include Inertial Upper Stage (IUS) missions which are used to transfer satellites from Low Earth Orbits to geosynchronous or interplanetary trajectories. The squadron also provides tracking and telemetry support on every Space Shuttle mission, and commercial customers. The 5<sup>th</sup> SOPS has two primary responsibilities. The first is the launch and early orbit support for all DSCS III satellites. The second is the on-orbit command and control of the DSCS II communications satellites. Additionally, the 5<sup>th</sup> SOPS provides tracking, telemetry, and commanding support for the National Oceanic Atmospheric Administration (NOAA), the Geostationary Operational Environmental Satellite (GOES) and the Total Ozone Mapping Spectrometer-Earth Probe (TOMS-EP) satellites.

**6<sup>th</sup> SOPS** is located at Shriever AFB, and is responsible for back-up command and control of the Defense Meteorological Satellite Program (DMSP). In May 1994, President Clinton directed the convergence of the DMSP program with NOAA's Polar-Orbiting Environmental Satellite (POES) program. The POES program currently provides weather data to civilian and military users. Primary DMSP operations have been relocated to Suitland, Maryland, NOAA's satellite control center.

**7<sup>th</sup> SOPS** is located at Shriever AFB and is the first Air Force Reserve unit assigned to AFSPC. The mission of this squadron is to augment the SOPS's of the 50<sup>th</sup> Space wing. These activities include responding to satellite emergencies, launch and early orbit, day-to-day routine operations and satellite end of-life disposal for the GPS and Defense Support Program (DSP) satellites. Future plans call for expanding the mission to include support for other programs.

**20<sup>th</sup> Air Force.** AFSPC has delegated the day-to-day management of our ICBM forces to the 20<sup>th</sup> Air Force, headquartered at F.E. Warren AFB, Cheyenne, WY. Its mission focuses on deterring conflict with ICBM's that provide a quick-reacting, inertially guided, highly survivable component to America's nuclear Triad. Missiles are dispersed in hardened silos to protect against attack and are connected to an underground launch control center through a system of hardened cables. Launch crews, consisting of two officers, perform round-the-clock alert in a launch control center. A variety of communications systems provide the NCA with highly reliable, virtually instantaneous direct contact with each launch crew. Should command capability be lost between the launch control center and remote missile launch facilities, specially-configured EC-135 airborne launch control center aircraft automatically assume command and control of the isolated missile or missiles. Fully qualified airborne missile combat crews aboard airborne launch control center aircraft would execute the NCA orders. The 20<sup>th</sup> Air Force units include: the 90<sup>th</sup> Missile Wing, F.E. Warren AFB, WY.; the 91<sup>st</sup> Missile Group, Minot AFB, ND; and the 341<sup>st</sup> Missile Wing, Malmstrom AFB, MT

**SPACE Warfare Center.** The Space Warfare Center (SWC), at Shriever AFB, supports the warfighter through operational testing and tactics development for space-related systems. By working with the theater commanders, the SWC personnel are able to integrate space systems into exercises and war plans. They also develop concepts and prototypes to employ emerging technologies for advanced space systems and missions. For example, among its initiatives is Project Hook—a combination of GPS navigation and survival radios designed to improve search and rescue operations for downed pilots. Project Hook essentially takes the "search" out of "search and rescue" by pinpointing the location of the pilot on the ground and relaying it via "burst transmission" to a Search and Rescue Center. The Multi-Source Tactical System (MSTS), another SWC initiative, provides a six-layered picture of the operational theater for the aircrews. It combines tactical, intelligence and digital mapping information with real-time Airborne Warning and Control System (AWACS) information to upgrade flight crews en route to their targets or drop zones. Overall, there are more than 30 initiatives currently underway in the SWC to improve the tactical use of space by warfighters. The SWC is also



developing space models and simulations for inclusion in war gaming centers around the world for all the services. They are developing, through their deployable Forward Space Support in Theater (FAST) teams, operational plans for theater commanders that provide access to space assets and training in their use. Finally, the center is developing courses to teach space operators how to wage war so they can better understand and plan for space support to warfighting missions.

**Air Force Space Battlelab.** The Air Force Space Battlelab at Shriever AFB, CO, is responsible for developing and testing innovative military space concepts. Because the pace of technology and innovation is faster than the current resource constrained planning, programming, and budgeting process can accommodate, the Battlelab creates an environment where innovative concepts can be harvested and rapidly evaluated, leading to more responsive fielding of proven concepts. The objective of the Battlelab is to provide proven operations and logistics concepts, which can be assimilated into Air Force organizational, doctrinal, training, and/or acquisition efforts. Table 2-2 summarizes all major AFSPC units.

<b>Table 2-2. Air Force Space Command (AFSPC) Major Units</b>		
<b>UNIT</b>	<b>BASE</b>	<b>WEAPON SYSTEM/ ACTIVITY</b>
14 <sup>th</sup> Air Force	Vandenberg AFB, CA	Provides day-to-day management of AFSPC space forces
21 <sup>st</sup> Space Wing	Peterson AFB, CO	Missile Warning Operations
721 <sup>st</sup> Space Group	Cheyenne Mountain AS, CO	Communications Maintenance Support
30 <sup>th</sup> Space Wing	Vandenburg AFB, CA	DoD, civil, and commercial spacelift
45 <sup>th</sup> Space Wing	Patrick AFB, FL	DoD, civil and commercial spacelift
50 <sup>th</sup> Space Wing	Shriever AFB, CO	Satellite Operations and AFSCN
750 <sup>th</sup> Space Group	Onizuka AS, CA	AFSCN operations
20 <sup>th</sup> Air Force	F.E. Warren AFB, WY	Manages ICBM force
90 <sup>th</sup> Space Wing	F.E. Warren AFB, WY	150 Minuteman-III and 50 Peacekeeper ICBMs
91 <sup>st</sup> Space Wing	Minot AFB, ND	150 Minuteman-III ICBMs
341 <sup>st</sup> Space Wing	Malmstrom AFB, MT	200 Minuteman-III ICBMs
Space Warfare Center	Shriever AFB, CO	Tactics for Space Systems
Air Force Battlelab	Shriever AFB, CO	Space applications R&D
20 <sup>th</sup> Space Surveillance Squadron	Eglin AFB, FL	Space Surveillance and Missile Warning
2 <sup>nd</sup> Space Warning Squadron	Buckley ANGB, CO	Missile Warning
5 <sup>th</sup> Space Warning Squadron	Woomera AS, AUS	Missile Warning
6 <sup>th</sup> Space Warning Squadron	Cape Cod AS, MA	Missile Warning
7 <sup>th</sup> Space Warning Squadron	Beale AFB, CA	Missile Warning
1 <sup>st</sup> Satellite Operations Squadron (SOPS)	Shriever AFB, CO	Command and control for DSP, GPS, and TAOS
2 <sup>nd</sup> SOPS	Shriever AFB, CO	NAVSTAR GPS
3 <sup>rd</sup> SOPS	Shriever AFB, CO	DSCS
4 <sup>th</sup> SOPS	Shriever AFB, CO	MILSTAR
5 <sup>th</sup> SOPS	Onizuka AS, CA	NATO IV/SKYNET
6 <sup>th</sup> SOPS	Shriever AFB, CO	DMSP back-up Command and Control
7 <sup>th</sup> SOPS	Shriever AFB, CO	AF Reserve Unit

## **North American Aerospace Defense Command (NORAD)**

President Franklin Delano Roosevelt and Canadian Prime Minister Mackenzie King issued the 'Ogdensburg Declaration' in August 1940. It voiced the concept of joint defense. At war's end, collective security for continental defense remained of vital interest to both nations. In February 1947, Ottawa and Washington announced the principles of future military cooperation that included consultation on air defense issues.

On August 1, 1957, the U.S. Secretary of Defense and the Canadian Minister of National Defence put the plans into action. It was then that they announced a binational agreement for a system of centralized operational control of air defense forces under an integrated command located in Colorado Springs.

The agreement signed by the two governments on May 12, 1958, set NORAD as the first and only successful binational command. In the agreement between the United States and Canada, NORAD provides a framework for cooperative defense planning and operations between both governments for the defense of North America.

After its establishment, the new binational command started working on a secure and safe home from which to operate. To increase the chances for survival, the center was moved in the mid-'60s from an above-ground and vulnerable building in Colorado Springs to the granite-shielded security of Cheyenne Mountain, then about seven miles south of the city.

NORAD is responsible to the heads of both governments for surveillance and control of the airspace of Canada and the United States; warning and assessment of an aerospace attack on North America; and, providing an appropriate response should deterrence fail.

Surveillance: For control of its North American airspace, NORAD maintains an extensive radar network throughout the U.S. and Canada. Additionally, the Commander in Chief (who is also the Commander of U.S. and Air Force Space Commands) has access to a wide array of space-borne sensors. These sensors are capable of detecting and tracking missile launches from anywhere in the world, and surveillance and monitoring aircraft suspected of smuggling illegal drugs into North America.

Warning and Assessment: To accomplish its warning and assessment role, NORAD maintains an Integrated Tactical Warning/Attack Assessment (ITW/AA) system. With information from the ground-based and space-based sensors, CINCNORAD can provide timely, reliable, and unambiguous warning of any attack against North America. In 1994, NORAD detected and analyzed over 200 missile launches worldwide, and, with the proliferation of ballistic missile technology, that number is expected increase dramatically in the future.

Response: NORAD's response capability is provided by a network of alert fighters along the periphery of North America. U.S. F-15s, and F-16s and Canadian F-18s stand ready to intercept and if necessary to engage any air breathing threat to the continent.

### **The NORAD/United States Space Command Collocated Command Center**

The heart of the Cheyenne Mountain AFB, underground complex is the NORAD/USSPACECOM Command Center. Within the center, the NORAD/USSPACECOM CINC and battle staff receives immediate warning and surveillance information from a worldwide system of ground and space-based sensors. Computers in the center translate and display the information on maps of North America and the world to give the battle staff a realistic picture of current situations. With its communications "hot" lines, the command center staff can contact the Pentagon or White House, U.S. Strategic Command, Canadian Forces Headquarters in Ottawa, other aerospace defense system command posts, and major military centers around the world. USSPACECOM supports the NORAD mission by manning the missile warning, space control, communications and intelligence centers.

### **Department of the Navy**

The Department of the Navy, like the other service departments, is responsible for providing forces for the strategic defense of the United States. Is charged with coordinating with the others to develop doctrines, procedures, and equipment for space operations. The Navy is specifically assigned responsibility for sea-based launch and space support missions. Additionally, the Navy is assigned missions such as maritime reconnaissance, antisubmarine warfare and mine warfare that may have unique applications for space systems. The Navy is the primary tactical user of space systems support services, and virtually every ship in the fleet and every unit of the fleet Marine force is equipped to receive this information. Over 85% of all satellite signal intelligence output provided to our military forces is used by the Navy and Marine Corps. Because of this strong reliance on space systems, the Navy has exerted significant influence in development and operation of space systems in the 1980s and early 1990s. Rather than relying on space systems support from the Air Force, the Navy is now competing with other services for both development and operation of the systems upon which it relies. It is reasonable to expect this trend to continue throughout the present decade.

**NAVY SPACE SYSTEMS DIVISION.** Within the Office of the Chief of Naval Operations (CNO), the Director of Space, Information Warfare, Command and Control (SIWC2) (N6) is assigned responsibility for centralized coordination of policy, planning, and integration for Navy command, control and communications; space exploitation; space defense matters; reconnaissance; ocean surveillance; and communications security. N6 sponsors Navy communications systems for command and control, space communications systems, navigation and environmental sensing systems, and support equipment.

The Navy Space Systems Division is responsible for developing a composite program for the Navy's use of space systems to perform surveillance, communications, navigation, command and control, environmental sensing, targeting, and warning. N63 is the principal point of contact within the Navy for command and control space matters, including policy and planning for space exploitation and the defense of space systems. This office also ensures that Navy space systems meet the needs of the operational commanders, including joint commands, and represents the Department of the Navy (DON) on interdepartmental, DoD, and national committees related to space systems.

The staff of the Director, Navy Space Systems, assesses future satellite and space system concepts and applications as they relate to the overall Navy command and control plan. They also validate requirements for space systems; coordinate with the OPNAV warfare and platform sponsors to ensure that space systems are responsive to operational requirements; maintain liaison with the other services and federal agencies for space system utilization; and identify training needs related to space systems support. The division also sponsors NAVSPACECOM initiatives within OPNAV.

**Space and Naval Warfare Systems Command.** The Space and Naval Warfare Systems Command (SPAWAR), San Diego, Ca., provides material, acquisition and life-cycle support to the Navy and Marine Corps for space systems; command, control, communications, and intelligence (C<sup>3</sup>I) systems; and surveillance. SPAWAR also develops force warfighting architecture and requirements integration, including space applications, for the Department of the Navy. It also manages Navy Research and Development Centers.

The command was established in 1966 as the Naval Electronic Systems Command (NAVELEX) under the Chief of Naval Material. The Naval Material Command was disestablished in 1985 and NAVELEX became the Space and Naval Warfare Systems Command. With the reorganization, the Department of the Navy placed new emphasis on space systems and undersea warfare programs.

As the manager of the Navy Research and Development Centers, SPAWAR controls seven Navy laboratories, four university laboratories, and eight engineering centers. Including the systems command staff, SPAWAR comprises nearly 30,000 military and civilian personnel.

**NAVAL SPACE COMMAND.** The Naval Space Command (NAVSPACECOM) is headquartered at Dahlgren, Virginia. The command was established in 1983 to strengthen operational control of naval space systems and provide a focal point for operational naval space matters. The commissioning of NAVSPACECOM culminated a series of initiatives to consolidate the Navy's extensive space efforts. Other initiatives in the early 1980s included formation of the Navy Space Systems Division on the staff of the Chief of Naval Operations; establishment of annual Naval Space Symposiums to examine Navy and Marine Corps roles and activities in space; development of the Space Operations and Space Systems Engineering

curricula at the Naval Postgraduate School; and the assignment of a flag officer as Director, Navy Space Project Office to manage Navy space acquisition efforts.

NAVSPACECOM is the naval component of USSPACECOM. As such, the command is responsible for organizing, training, equipping, and administering Navy and Marine Corps forces in support of USSPACECOM missions. NAVSPACECOM provides the Navy and Marine Corps perspective in planning for DOD space system support to maritime and amphibious operations; ensures integration of Navy requirements in USSPACECOM operating plans; responds to USCINCSpace-directed tasking; commands assigned forces; and conducts planning for DOD space operations in support of naval strategic and tactical missions.

Efforts to fulfill this mission encompass operations, space intelligence, awareness and education, and future planning. NAVSPACECOM maintains a constant surveillance of space and provides satellite data as directed by the Chief of Naval operations and higher authority to fulfill Navy and national requirements; supports the U.S. Space Command as a dedicated sensor in the worldwide Space Surveillance Network (SSN); provides satellite observations, elements, and look angles to the Space Control Center (SCC); functions as the Alternate Space Control Center (ASCC) that serves as the backup for the SCC; manages the Navy space-based communications systems, including the Fleet Satellite (FLTSAT) Communications System, LEASAT and the UHF Follow-On (UFO); the Naval Space Surveillance System; the Relocatable Over-The-Horizon Radar (ROTHR) System; and participates in the development and operation of other communications, navigation, and surveillance systems. Space intelligence involves assessing the threat to the space systems upon which our forces rely, using our own space systems to identify air and surface threats. In addition to supporting education and training programs throughout the fleet, the command sponsors a Chair in the Space Operations curriculum at the Naval Postgraduate School as well as a Space Chair in the Aeronautical Engineering curriculum at the U.S. Naval Academy. Finally, NAVSPACECOM determines operational requirements for space and space support systems, and also tracks applicable technology development on behalf of the CNO.

NAVSPACECOM is comprised of the headquarters command and two subordinate commands: the Naval Satellite Operations Center (NAVSOC) and the Fleet Surveillance Support Command (FSSC).

A Rear Admiral (O-7) with extensive operational experience commands NAVSPACECOM. The Deputy Commander is a Marine Colonel (O-6), who provides a Marine Corps perspective on the utilization of space assets. A Technical Director, a senior civilian, who provides extensive experience in space system operations and development, assists both. The remaining staff is organized into functional divisions for management support (N1), intelligence (N2), operations (N3), logistics (N4), planning (N5), information systems (N6), and training (N7).

NAVSPACECOM manages the use of existing satellites and space support systems by the Navy and Marine Corps, and assists in the development of future space systems to meet the projected needs of the fleet. A significant current initiative involves managing the FLTSAT Extra High Frequency (EHF) Package (FEP) program. FEP modules have been added to FLTSAT 7 and 8 (the last two FLTSAT spacecraft) to provide a space-based test bed for EHF technology and the development of EHF communications terminals for the MILSTAR satellite communications program.

Other initiatives include the development and deployment of the Joint Tactical Ground Station (JTAGS) for the enhanced capability to detect tactically significant targets using the Defense Support Program (DSP) satellites; provides multi- and hyper-spectral imagery (MSI) from LANDSAT IKONOA and SPOT Earth resources spacecraft to assist naval forces with exercise and strike planning, provide updated maps and charts, and enhance intelligence and surveillance capabilities; assessing the global space threat, prioritizing enemy space assets, and providing targeting data for the proposed kinetic energy anti-satellite system; the development and operation of tactical satellites (TACSATS) to provide theater-level communication, tactical surveillance, and environmental monitoring; demonstration of a recoverable sea-launched booster (SEALAR); the application of military man-in-space (MMIS) to naval operations; and development of the Space-Based Wide Area Surveillance (SBWAS) system. The Navy is also assisting other services in developing plans and programs for Ballistic Missile Defense (BMD), a personal computer-based Multi-spectral Imagery (MSI) workstation, and a standardized satellite command and control system.

NAVSPACECOM operates a unique space sensor as part of the SSN. A network of field stations produces a fence of electromagnetic energy approximately 5,000 nautical miles long, extending across the continental United States and portions of the Atlantic and Pacific Oceans. In the north-south direction, the fence is approximately 2 miles wide and can detect objects at a height of 15,000 nautical miles. Together, NAVSPACECOM's nine field stations comprise one of the largest antenna systems in the world. With a total length of over 15 miles, each antenna site incorporates 150 miles of transmission lines, 10,000 feet of steel posts, and 18,000 dipoles.

NAVSPACECOM's six receiver sites receive the transmitted energy reflected from satellites as they pass through the fence. Each receiver site has individual antennas spaced at precise intervals. The longest antenna at each site is known as the alert antenna, because it is more sensitive and can detect a signal before the remaining antennas. It then electronically alerts the system controller to the presence of a target so that the receiver may be tuned to the precise frequency of the reflected energy from the satellite. Two receiver sites, Elephant Butte and Hawkinsville, are known as high-altitude sites. Their antenna arrays have higher gain and their electronics are configured to make them more sensitive to the reflected energy from higher altitudes.

The receiver sites collect over 1 million satellite detections, or observations, each month. This data is transmitted to NAVSPACECOM headquarters over conditioned telephone lines and upon arrival, is ready for processing within seconds of fence penetration. The lines of sight from each station are then calculated and used to pinpoint the object in space.

Satellite identification is made by matching the observed fence crossings with the predicted position. These observations are used to update the database of orbital elements at headquarters and generate new fence crossing predictions. The computers can also use these orbital elements to generate a wide variety of data products for use by USSPACECOM, the fleet and other military and scientific agencies.

NAVSPACECOM staffs a command center 24 hours a day, 7 days a week, to maintain operations of the network. Command center personnel monitor launches, maneuvers, and breakups of both foreign and domestic satellites. An up-to-date catalog of all objects in space is maintained by NAVSPACECOM. This catalog, which serves as a direct backup to the space object catalog kept by USSPACECOM, contained nearly 10,000 objects in 1998. In recent years it has grown steadily at a rate of approximately 8% per year. In addition, a small group of analysts is dedicated to the evaluation of unusual satellite on-orbit activity. These analysts maintain an accurate database on all foreign launches and provide observations and conclusions about satellite orbital behavior using tailored databases and information from other NAVSPACECOM analysts as well as the Space Surveillance Network.

**NAVAL SATELLITE OPERATIONS CENTER.** The NAVSOC, formerly called the Navy Astronautics Group (NAG), provides telemetry, tracking and control (TT&C) for experimental spacecraft, and recently provided TT&C for GEOSAT, an oceanographic and geodetic survey satellite. Additionally, NAVSOC can remotely operate the two Fleet Satellite Extremely High Frequency Package (FEP) Operations Centers (FEPOCs), located in Maine and Massachusetts, to coordinate testing of FEP communications systems and related terminals.

The NAG was commissioned in April 1962 to provide an accurate, all-weather positioning capability to naval forces operating around the world via TRANSIT satellites. During TRANSIT operations from 1965 to 1998, the TRANSIT/NAVASTROGRU system maintained 99.86% reliability. Recognizing the transition from a research and development facility in its early years to an operational satellite control center, the command's title was changed in June 1990 to the Naval Satellite Operations Center (NAVSOC). The name change reflects a growing commitment by the Department of the Navy to better exploit space systems in support of our operational forces.

The mission of the NAVSOC is to maintain and operate satellite systems (including spacecraft and ground-based components and subsystems) to fulfill naval and national requirements. It is the only Navy organization that performs all space-related functions, including satellite launch support, orbit insertion and adjustments, satellite commanding and

system monitoring, network scheduling, and providing technical assistance with new satellite system developments and concepts.

NAVSOC headquarters is located at Point Mugu, California. Personnel in the Satellite Operations Control Center at the headquarters schedule and monitor all operations for assigned satellites, evaluate telemetry, and compute precise satellite orbit trajectories. Four Tracking and Satellite Contact Facilities communicate with the satellites to provide tracking and control, the operation of which is discussed in detail in Chapter 7 of this manual.

The command has also established a detachment in Colorado Springs, Colorado, to serve as an on-sight representative to Air Force Space Command, provide technical expertise, and oversee Air Force Satellite Control Network operations of the Fleet Satellite Communications System.

The TRANSIT navigation system was phased out when the NAVSTAR Global Positioning System (GPS) became fully operational in the mid-1990s. It has been proposed that NAVSOC provide TT&C for the Submarine Laser Communications satellite system, the Fleet Satellite follow-on program, and the Space-Based Wide Area Surveillance program, all under development. NAVSOC is also developing sea-based, mobile TT&C systems to provide survivable satellite command and control, and participates in locating sources of radio frequency interference (RFI).

**NAVAL RESEARCH LABORATORY.** The Naval Research Laboratory (NRL) is the Navy's principal in-house research laboratory for the physical and engineering sciences. Established under the command of the Chief of Naval Research, NRL is responsible for conducting a broad-based, multidisciplinary program of scientific research and advanced technological development of new and improved materials, equipment, techniques, systems, and related operational procedures for the Navy. The Laboratory conducts exploratory and advanced development programs in response to identified and anticipated Navy needs. It is the lead agency responsible for the development of space technology for the Navy.

NRL has been responsible for both satellite technology and specific satellite programs. The Laboratory directed the development and operation of "Vanguard"; satellite computer and memory systems; satellite-based experiments; technology and the test bed for the Global Positioning System; and, most recently, the Low-Power Atmospheric Compensation Experiment (LACE) satellite for the Strategic Defense Initiative (SDI or "Star Wars") program.

The Laboratory occupies approximately 130 acres on the Potomac River in Washington, D.C. The Chesapeake Bay Detachment in Chesapeake Beach, MD, and the Underwater Sound Reference Detachment in Orlando, FL, are NRL's major remote facilities. The Laboratory also maintains 12 other remote facilities in the District of Columbia, Maryland, Virginia, Florida and Alabama.



The mission of the Laboratory is carried out by four science and technology directorates supported by the Executive Directorate and the Business Operations Directorate.

**NAVAL COMPUTER AND TELECOMMUNICATIONS COMMAND.** The Naval Computer and Telecommunications Command (NAVCOMTELCOM) is a shore activity under the direct command of CNO. The command was established in 1967 as the Naval Communications Command, reorganized in 1973 as the Naval Telecommunications Command, and merged with the Naval Data Automation Command in 1990 to form NAVCOMTELCOM. The command is responsible for operating and maintaining the Naval Telecommunications System (NTS), a network of equipment and subsystems that provide telecommunications and data processing for the operation, command and control, and administration of the Navy.

NAVCOMTELCOM exercises configuration control of the Naval Telecommunications System (NTS); serves as the operations and maintenance manager of elements of the Defense Communications System assigned to the Navy; supports Fleet Commanders in Chief in assuring the adequacy, effectiveness, and responsiveness of operational telecommunications; and provides technical support for non-tactical data processing systems that interact with common user communications networks, and publishes communications security (COMSEC) and COMSEC Material System (CMS) policy.

NAVCOMTELCOM manages the NTS and commands its major shore elements, which include four Naval Computer and Telecommunications Area Master Stations (NCTAMS), Naval Computer and Telecommunications Stations (NCTS), Naval Communication Units, Naval Communication Detachments, Naval Telecommunications Centers, Antisubmarine Warfare Support Communications Centers, special communications sites, the Naval Telecommunications Automation Support Center, the Naval Telecommunications Systems Integration Center, and the Naval Electromagnetic Spectrum Center.

The NCTAMS provide up link of Navy messages, weather broadcasts, and the distribution of tactical surveillance intelligence for the fleet broadcast portion of the FLTSATCOM system. NAVCOMTELCOM also manages the interfaces between the International Maritime Satellite (INMARSAT) system and the NTS for Military Sealift Command operations.

## **U.S. Marine Corps**

The Marine Corps uses space to achieve enhanced command and control capabilities. Marines use the space assets of other organizations to provide space-based combat support to amphibious forces. This is accomplished by placing a few Marines in select billets to leverage external assets as much as possible, and by purchasing the necessary ground stations and equipment to use existing and proposed systems. The Marines typically do not organize to

provide space support, but rather, provide support organized along functional areas, some of which use space systems to accomplish their mission. Typically, Marines interface with the following organizations to obtain their required space support:

U.S. Space Command. Several Marines with the Military Occupational Specialty (MOS) 9666 are located at USSPACECOM, providing joint support to CINCSPACE.

Naval Space Command. Marines are an integral part of the NSC staff. Both active and reserve Marines work on matters of interest to both naval services, including doctrinal issues, operations access to space systems, and space systems acquisition. One U.S. Marine Reserve unit is associated with NSC.

Army Space Command. Marine reservists have supported ARSPACE in the past, particularly in the area of multi-spectral imaging.

**COMMANDANT OF THE MARINE CORPS (CMC).** The Commandant works through his staff at Headquarters, Marine Corps, to direct policy and budgetary actions affecting space-related systems. Graduates of the Naval Postgraduate School, Space Operations Curriculum, who have the 9666 secondary MOS work at CMC, Code PL8. CMC is a focal point for coordination of Marine Corps space policy. Access for Tactical Exploitation of National Capabilities (TENCAP) is obtained via Marine Corps headquarters, as well as the Naval Space Command.

## **Department of the Army**

In addition to the shared responsibilities of providing forces for the strategic defense of the U.S. and coordinating with the other services for space operations, the Department of the Army is responsible for exploiting space activities that contribute to the successful execution of Army missions. Although not assigned sole responsibility for their development, the Army is particularly interested in systems related to mapping, charting, and geodesy. Like the other services, the Army uses space systems for communications, navigation, surveillance, and environmental monitoring to accomplish its primary mission of air/land combat operations in support of national objectives.

The Army has been active in space activities since late 1940s. Early efforts included the development of boosters, launch vehicles, and satellites, including America's first satellite, "Explorer" I. Today, like the other services, the Army is capitalizing on space systems to provide increased capability to air and ground forces.

Future Army requirements will place increased emphasis on deployment of light, mobile forces assisted by space systems. The Army Space Policy states that:

*"Successful implementation...will require development of a pool of Army space expertise and judicious planning, to include development of concepts, requirements, and a long-term management strategy. Army plans and evolving space architecture must capitalize on national and joint programs, preserving options to support initiatives that fulfill Army requirements. Implementation of this policy demands a visionary outlook to exploit fully evolving space capabilities."*

Like the Navy, the Army has recently begun to exert more influence in the development of space systems, and is competing with other services for space programs. Under the direction of the Deputy Chief of Staff for Operations (DCSOPS) at Headquarters Department of the Army, the Army is developing plans and operating concepts for Strategic Defense System elements that include ground-based radar, surveillance and tracking systems, and ballistic missile defense and anti-satellite weapons systems.

**U.S. ARMY SPACE AND MISSILE DEFENSE COMMAND (SMDC).** The Army Space and Strategic Defense Command (SSDC) was created in 1992 to unite key Army space organizations under a Lieutenant General. This command was a combination of two former Army commands, the Army Space Command (ARSPACE), located in Colorado Springs and the Strategic Defense Command in Huntsville, Alabama. Since 1992, the Army Space Program Office (ASPO), which runs the Army TENCAP program; and the Army Space Technology Program, which guides Army R&D activities, have joined SMDC. In October 1997, Army SSDC was renamed Army Space and Missile Defense Command (SMDC). The headquarters for SMDC, in Arlington, Virginia, reports directly to the Army's Deputy Chief of Staff for Operations (DCSOPS).

## **Mission**

U.S. Army SMDC activities in Huntsville trace their lineage to Werner von Braun and the Redstone Arsenal space activities of the 1950s. Today, SMDC maintains a place within DoD as a superior research facility supporting not only Army initiatives, but the Ballistic Missile Defense Organization, the Advanced Research Program Agency (ARPA) and a myriad of other DoD research and applications initiatives. SMDC at Huntsville is organized into two main centers: the Missile Defense and Battlefield Integration Center supporting modeling and simulation activities; and the Missile Defense and Space Technology Center focusing on space and strategic defense-oriented research and development.

Primary functions of SMDC include:

- Operation of the Advanced Research Center (ARC), a government-owned, contractor-operated research center for ballistic missile defense activities. ARC is a

part of the National Testbed and works with the Joint National Test Facility (JNTF) at Shriever AFB.

- Operation and maintenance (O&M) of the High Energy Laser System Test Facility (HELSTF) at White Sands Missile Range, New Mexico.
- Development of technologies associated with Army space capabilities.

## **SMDC Organizations**

**U.S. Army Space Command (USARSPACE).** The Army Space Command (ARSPACE) was created in 1988 and functioned as the Army component command to USSPACECOM. ARSPACE was re-designed as the U.S. Army Space Command (USARSPACE) in 1994 to differentiate the original ARSPACE in Colorado from the headquarters in Virginia.

Beginning with DESERT SHIELD/DESERT STORM and continuing through activities in Haiti and Bosnia, ARSPACE has established a presence within the Army as an important provider of space capabilities. ARSPACE routinely trains with units and may provide contingency support. ARSPACE also provides equipment and expertise during major training exercises. ARSPACE continues to focus heavily on tactical, operational, and strategic applications as demonstrated by the following list of missions and functions managed by ARSPACE:

- Theater Missile Defense Tactical Operations Center (TMDTOC)
- Joint Tactical Ground Station (JTAGS)
- Army Space Support Teams (ARSST)
- Army Space Exploitation Demonstration Program (ASEDP)
- Payload management of the Defense Satellite Communications System (DSCS)
- Western Test Range and Space Surveillance Operations at Kwajalein Atoll

USARSPACE supports the Army by assuring access to the nation's space resources as well as planning for future space systems. By executing control of DSCS payloads through its subordinate elements, USARSPACE provides the warfighter with assured access to satellite communications to support command, control and communications needs.

USARSPACE delivers relevant space capabilities to tactical Army units and deploys Army Space Support Teams to major units during crisis and exercises. These teams deliver equipment and expertise to empower tactical forces with satellite-based communications, weather, positioning, mapping and intelligence capabilities.

USARSPACE supports tactical missile defense by operating warning and command systems in a ground theater of operations. The JTAGS and the Army Tactical Missile Defense

Elements focus land components efforts to protect friendly forces, intercept hostile missiles and counterstrike enemy launch systems.

USARSPACE advances Intelligence Preparation of the Battlefield (IPB) by delivering terrain and weather imagery from commercial and military satellite-derived information is efficiently exploited in command and control systems.

USARSPACE is currently involved in the design of future satellites to include Space Based Infrared System (SBIRS), DSCS Follow-On, GPS Block 2F and MILSTAR.

**Army Space Program Office (ASPO).** The U.S. Army Space Program Office (ASPO), located in Alexandria, Virginia provides the Army's principle interface to the National Intelligence community. ASPO has the Army's charter to field, train and maintain a limited number of Tactical Exploitation of National Capabilities (TENCAP) systems to Army tactical organizations. At this time, ASPO nominally falls under SMDC for administrative and command and control purposes while retaining funding ties directly to the Department of the Army.

### **Other Space Support Organizations**

**Army Training and Doctrine Command (TRADOC).** HQ TRADOC at Ft. Monroe, Virginia is the home of the Army's "Space Command and Control Warfare Directorate," which focuses Army requirements for space capabilities into formal statements of need. These are then subsequently passed to material developers for acquisition or development.

The Army regards requirements as either short-term or long-term, roughly corresponding to the time frame of support. Short-term, or operational requirements, are strictly the responsibility of specific operational commands. For instance, requirements for a tactical communications capability requested by an infantry brigade, may be acted upon by the appropriate element of ARSPACE. ARSPACE would then validate the requirement, establish the means to support the request then dispatch a team or system to address the need.

Requirements for long term items such as changes to doctrine or training are passed through the training and Doctrine Command from TRADOC schools and centers. This is where functional experts attempt to express future Army needs in a formal requirements definition process. An example would be the estimation by the Signal School that a capability would be needed in the year 2000 to support the warfight tactics and technologies of a future tactical application. The Space and C2 Directorate at TRADOC formally receives such requirements for space from Space Action Officers. Action officers are located in many of the Army's doctrine and training centers and schools and examine the requirements in lieu of other cross-function requirements.

TRADOC Battle Labs have been in existence since 1966 and serve as rapid prototyping and evaluation centers for various battlefield functions. The labs have demonstrated steadily increasing appetites for space systems or information derived from space systems.

**Communications Engineering Command (CECOM).** Although the SMDC provides some material development capabilities, the Army's CECOM at Ft. Monmouth, New Jersey provides communications oriented material developed under the Space and Terrestrial Communications Directorate and the Program Manager for Satellite Communications (PM SATCOM).

**Army Corps of Engineers (COE).** The Army Corps of Engineers has been extremely active in the exploitation of space systems. Mainly, their work has been from applications or disciplines represented in the Topographic Engineering Center (TEC), Ft. Belvoir, Virginia, which has preformed limited fielding of space systems in conjunction with ASPO. The Program Manager for Combat Terrain Information Systems (PM CTIS) resides at TEC, and is responsible for the fielding and training of many systems. For example, the Multi Spectral Imager Processor (MSIP), which is now being fielded throughout the Army Topographic Engineering community. This is a result of joint TEC, TRADOC and ARSPACE initiatives to demonstrate the utility of space systems to Army tactical forces.

## **CIVIL SPACE ORGANIZATIONS**

Prior to the Soviet's launch of SPUTNIK I on 4 October 1957, the United States did not have a civil space program. The success of SPUTNIK I, followed closely by SPUTNIK II, galvanized the nation's leadership to recognize the potential strategic and international implications of the use of space.

The Navy was given the task of developing and launching the United States' first Earth-orbiting satellite. The Army, under the leadership of the noted German rocket scientist, Dr. Werner von Braun, modified a ballistic missile to launch our first satellite, EXPLORER II, in January 1958. After several spectacular launch attempt failures, the Navy succeeded in launching the Project Vanguard satellite on 17 March 1958 from a new, Navy built facility at Cape Canaveral, Florida.

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.** Following the success of the Navy's "Vanguard" satellite, the National Aeronautics and Space Act of 1958 was quickly enacted. The first National Space policy declared that "...it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind." In making this declaration, Congress created a new independent agency, the National Aeronautics and Space Administration (NASA). NASA's charter stated that the agency would be responsible for providing direction and control over all U.S. space activities "...except those activities peculiar to or primarily associated with the development of weapons systems, military operations, or the defense of the United States."

The new space agency absorbed an existing independent agency, the National Advisory Committee on Aeronautics (NACA), originally chartered in 1915 to advance aeronautical technology. NACA became the "aeronautics" part of NASA. The transfer of approximately 200 Navy scientists and engineers from the Naval Research Laboratory, and a number of U.S. Army personnel all of whom had previous experience with launching spacecraft formed the "space" portion of NASA.

**NASA HEADQUARTERS.** NASA fulfills the responsibilities of the agency's statutory charter through the operation of five major space flight centers, four major research centers, and seven field installations all under the command and control of NASA Headquarters in Washington, D.C. NASA's responsibilities are described by the functions of the six principal program offices within NASA Headquarters and are discussed in the following chapter.

The **Office of Aeronautics and Space Technology (OAST)** is responsible for advanced development programs in aeronautics and space technology.

The **Office of Space Science and Applications (OSSA)** is responsible for NASA's research and development activities in astrophysics, planetary exploration, Earth environmental observation, materials processing, communications and data processing systems, and flight of the manned, reusable SPACELAB module carried aboard the Space Shuttle.

The **Office of Space Operations (OSO)** is responsible for providing trajectory tracking and communications to all NASA spaceflight programs. The OSO manages an integrated worldwide network of tracking and communications facilities including the Deep Space Network (DSN), the Spaceflight Tracking and Data Network (STDN), and the Tracking and Data Relay Satellite System (TDRSS).

The **Office of Space Station** has full program responsibility for the development of the manned, Earth-orbiting Space Station, *Freedom*.

The **Office of Commercial Programs** is responsible for ensuring that NASA-developed technology with commercial applications is made promptly available for use by private sector enterprise.

The **Office of Space Flight (OSF)** is responsible for the management and operations of the manned Space Shuttle Program (SSP), all U.S. civil unmanned launch vehicle operations, and development of NASA spaceflight centers, including the Johnson Space Center, Marshall Space Flight Center, Goddard Space Flight Center, and the Kennedy Space Center.

**JOHNSON SPACE CENTER.** Johnson Space Center (JSC) located in Houston, Texas, is NASA's principle center for the research, design, development, and test of manned spacecraft systems to include the International Space Station. It was established as the Manned

Spacecraft Center in 1961 with the move of the Space Task Group from the NASA Langley Research Center in Virginia. JSC's Mission Control Center has been NASA's command and control center for all manned spaceflight missions since the flight of Gemini 4 in June 1965. The center was renamed following the death of President Lyndon B. Johnson, a strong supporter of the nation's manned space program.

JSC plays a key role in the Space Shuttle program, including responsibility for the development of the Orbiter spacecraft, payload integration, and overall Shuttle integration. JSC is also responsible for the selection and training of astronauts, flight crew and flight controller training, Shuttle flight control, and control of experiments and payloads on board the Orbiter.

JSC also operates the White Sands Test Facility (WSTF) located on the Army's White Sands Missile Range near Las Cruces, New Mexico, in support of the Space Shuttle Propulsion System development. Nearby is the White Sands Space Harbor, an alternative-landing site for the returning Orbiter. Shuttle pilots practice landing approaches at WSSH using specifically modified shuttle training aircraft.

**KENNEDY SPACE CENTER.** The nation's first space launch on 24 July 1950 used a modified version of a captured World War II V-2 rocket. The V-2 attained an altitude of 10 mile's from the launch facility that was simply known as "Cape Canaveral." Renamed after the death of President John Fitzgerald Kennedy, the 140,000-acre Kennedy Space Center (KSC) is the primary NASA center for the integration, test, and launch of all of the nation's manned spacecraft and the majority of unmanned expendable launch vehicles. Manned launches from "the Cape" include the Mercury, Gemini, Apollo, Apollo-Soyuz, and Space Shuttle programs, and the world's first space station, Skylab.

KSC has full responsibility for all ground processing of the Space Shuttle including pre-flight assembly and checkout, launch, and landing recovery operations. KSC provides a full ground support team to the NASA Ames-Dryden Flight Research Center for support of Orbiter landings and subsequent ferry flight of the Orbiter back to KSC atop a NASA 747 Shuttle carrier aircraft. KSC is designated as the secondary landing site for the Orbiter.

In addition to manned space launches, KSC has been the launch site for many unmanned satellites, including all U.S. government communications satellites, geosynchronous weather satellites, and interplanetary probes such as Pioneer, Viking, and Voyager.

Under an agreement with the U.S. Air Force, NASA shares many of the expendable launch vehicle and support facilities including the 10,000-mile-long Eastern Test Range headquartered at the adjacent Cape Canaveral Air Force Station (CCAFS). Boosters launched from CCAFS include the Atlas, Delta, Titan, and many early developmental rockets. KSC personnel also support high inclination NASA launches from the Western Test Range at Vandenberg Air Force Base, California.



**MARSHALL SPACE FLIGHT CENTER.** The Marshall Space Flight Center (MSFC) was the home of the German rocket scientist Dr. Werner von Braun and his team of engineers. Located on the Army's Redstone Arsenal, MSFC's primary responsibility is for the development of large spacecraft propulsion systems and launch vehicles. The "Apollo" Saturn V moon rocket, "Saturn" 1B, and other major launch vehicles were developed by MSFC engineers.

In support of the Space Shuttle program, MSFC has principal responsibility for the development and production of the reusable solid rocket boosters, the external tank, and the reusable main engines. MSFC is also the focal point for NASA, in cooperation with the European Space Agency (ESA), for the design and operation of the modular reusable SPACELAB laboratory carried aboard the Orbiter, as well as many of the experiments carried aboard SPACELAB. MSFC also had systems engineering and integration responsibility for the Hubble Space Telescope.

**GODDARD SPACE FLIGHT CENTER.** Named for American rocket pioneer, Dr. Robert H. Goddard, the Goddard Space Flight Center (GSFC) is responsible for the development and operations of unmanned earth-orbiting spacecraft, and serves as the center of NASA's worldwide spaceflight tracking and communications networks. In addition, GSFC serves as the program manager for the NASA expendable launch vehicle program.

Some of GSFC's major spacecraft projects include:

- Solar Maximum Mission satellite (Solar Max);
- Cosmic Background Explorer (COBE);
- Gamma Ray Observatory (GRO);
- Upper Atmospheric Research Satellite (UARS);
- TIROs series NIMBUS satellites; and
- LANDSAT (formally Earth resources technology) satellite series.

GSFC is also responsible for operating and servicing the Hubble Space Telescope throughout its 15-year mission. As the hub of NASA's space tracking and communications networks supporting the Space Shuttle and other space systems, GSFC is responsible for the management and operation of the Spaceflight Tracking and Data Network, the Tracking and Data Relay Satellite Systems, and the NASA Communications Network (NASCOM). GSFC manages several NASA field installations including Wallops Flight Facility, the Space Telescope Science Institute, and the National Scientific Balloon Facility.

The Wallops Flight Facility (WFF) on Wallops Island, Virginia (formerly Chincoteague Naval Air Station), is one of the oldest and busiest flight test ranges in the world. Averaging over 300 launches per year, the WFF launches experiments to study the upper atmosphere and

space environment on vehicles ranging in size from small meteorological rockets to the four-stage Scout with orbital capability.

The Association of Universities operates the Space Telescope Science Institute (STScI), located at the Johns Hopkins University in Baltimore, M.D., for NASA for Research in Astronomy. The STScI is responsible for processing, analyzing, and displaying astronomical data transmitted from the Earth-orbiting Hubble Space Telescope.

The National Scientific Balloon Facility located near Palestine, Texas is responsible for launch and recovery support of high altitude scientific balloon-borne experiments.

**STENNIS SPACE CENTER.** NASA's smallest center, the Stennis Space Center (SSC), is the agency's primary center for the static test firing of large rocket engines. SSC construction started in October 1961 in preparation for full scale testing and flight acceptance test firing of the first (S-IC) and second (S-IIC) stages of the Saturn V launch vehicle. The test stands constructed to hold the Saturn S-IC stage remain today as the tallest structures in the State of Mississippi. Since 1975, SSC has used the former "Apollo" test stands for the static test firing and flight acceptance firing of the Space Shuttle Main Engines. SSC is also NASA's lead center for advance development of remote sensing and multi-spectral technology for Earth resources applications. Several Navy facilities are co-located at the SSC, including the Naval Oceanography Command, the Naval Oceanographic Office, the Naval Oceanic and Atmospheric Research Laboratory, and the Institute for Naval Oceanography.

**JET PROPULSION LABORATORY.** Operated for NASA by the California Institute of Technology, the Jet Propulsion Laboratory's (JPL) primary space-related responsibilities include the planetary exploration of the Earth and solar system with unmanned, automated scientific space probes, and the design and operation of the global Deep Space Tracking Network. Some of JPL's major missions include the "Ranger" and "Surveyor" lunar mapping missions, which paved the way for a manned lunar landing, the Mariner missions to Mars, Venus, and Mercury, the "Viking" Mars Observers and Landers, the "Voyager" missions to the outer planets, the "Galileo" mission to study Jupiter, and the Magellan radar mapping mission to Venus. JPL is also noted for development of digital image processing and computer enhancement techniques for analysis of remotely sensed data.

**LANGLEY RESEARCH CENTER.** As one of the original NACA research facilities, Langley Research Center (LaRC) is NASA's oldest center. LaRC's principal responsibility is basic research in aeronautics and space technology. LaRC was the home of the original "Mercury" astronauts and the Space Task Group before the construction of the JSC in Houston.

Using more than 40 wind tunnels, LaRC explores the full range of flight from general aviation and transport type aircraft, to hypersonic vehicles potentially capable of direct ascent to Earth orbit. Among LaRC developed Space Shuttle experiments is the Long Duration

Exposure Facility (LDEF), which was designed to determine the long-term effects of the space environment on typical spacecraft materials.

**LEWIS RESEARCH CENTER.** Lewis Research Center (LeRC) is NASA's lead center for research and development of advance technologies in aircraft air-breathing propulsion, space propulsion, space power generation, and satellite communication systems. LeRC has investigated many exotic forms of space propulsion including nuclear and electric rocket systems. LeRC was responsible for the development of the "Atlas" expendable launch vehicle and Centaur upper stage, and maintains technical management of both programs.

**AMES RESEARCH CENTER.** Named after Joseph F. Ames, the NACA's chairman for 12 years, Ames Research Center (ARC) was established in 1940 as a major aeronautical research laboratory. Located on Moffett Field Naval Air Station, CA, ARC has played significant roles in the development of military and civil aviation programs. As NASA's lead center for helicopter research, ARC also uses very large wind tunnels to conduct full-scale aircraft testing. ARC space exploration efforts continue to make history in step with the civil program's progress. The "Pioneer" series of unmanned probes, managed by ARC, were the first spacecraft to visit Jupiter, Saturn, and Venus. As the world's oldest operating spacecraft, "Pioneers" 10 and 11 are now the farthest man-made objects from Earth, as they continue their journey outbound from the solar system. ARC maintained contact with these historic spacecraft through the year 2000.

ARC also operates the Ames-Dryden Flight Research Facility (DFRC) at Edwards Air Force Base, CA. Specializing in flight research programs, Dryden has tested many major research aircraft, including the X-1, D-558, X-3, X-4, X-5, XB-70, and the X-15, which was piloted to world speed and altitude records of 4,500 mph and 350,000 feet. DFRC also plays a significant role in Space Shuttle operations. As the primary, end-of-mission landing site, DFRC was the location of the early series of approach and landing tests where the Orbiter ENTERPRISE was flown off the top of the NASA 747 shuttle carrier aircraft and glided to safe landings on the dry Edwards lake bed.

Major NASA facilities are shown in Figure 2-2 and are briefly described in the accompanying table.



Figure 2-2. Major NASA facilities.

1. NASA Headquarters, Washington DC, is responsible for management and direction of all agency programs;
2. NASA Johnson Space Center, Houston Texas, is responsible for all Space Shuttle operations, design and testing of manned spacecraft, and selection and training of astronauts;
3. NASA White Sands Test Facility, White Sands, New Mexico, a JSC field installation, is responsible for Space Shuttle propulsion testing, materials testing for space flight, and secondary landing sight for the Orbiters;
4. NASA Kennedy Space Center, Cape Canaveral, Florida, is responsible for assembly, pre-flight testing, launch, and landing recovery of the Space Shuttle;
5. NASA Marshall Space Flight Center, Huntsville, Alabama, is responsible for Space Shuttle Main Engines, External Tank, Solid rocket Booster, and Spacelab;
6. NASA Michoud Assembly Facility, East New Orleans, Louisiana, a MSFC field installation, is responsible for manufacture and assembly of the Space Shuttle External Tank;
7. NASA Slidell Computer Complex, Slidell, Louisiana, is responsible for computer services for the Michoud Assembly Facility;
8. NASA Stennis Space Center, Bay St. Louis, Mississippi, is responsible for testing of Space Shuttle main engines and remote sensing/multi-spectral imaging technology development;
9. NASA Goddard Space Flight Center, Greenbelt, Maryland is responsible for Earth-orbiting scientific satellites and the space tracking and communication networks;
10. Wallops Flight Facility, Wallops Island, Virginia, a GSFC field installation, is responsible for launching small rockets with scientific payloads;
11. Space Telescope Science Institute, Baltimore, Maryland, a GSFC field installation, is responsible for processing, analysis and display of Hubble Space Telescope astronomy data;
12. NASA National Scientific Balloon Facility, Palestine, Texas, a GSFC field installation, is responsible for launch and recovery support of high-altitude scientific balloon experiments;
13. NASA Jet Propulsion Laboratory, Pasadena, California, is responsible for unmanned automated space probes to explore-the solar system;
14. NASA Langley Research Center, Hampton, Virginia, is responsible for research in advance aeronautics and space technology;
15. NASA Lewis Research Center, Cleveland, Ohio, is responsible for research and development of advanced aircraft and spacecraft propulsion systems, space power systems, and satellite communications;
16. NASA Ames Research Center, Moffett Field, California, is responsible for advanced research in aeronautical and space technology;
17. NASA Ames-Dryden Flight Research Facility, Edwards Air Force Base, California, a field installation of ARC, is responsible for flight test of new aircraft and spacecraft and primary end-of-mission landing site for the Orbiters.

## **NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)**

A component of the US Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA), is responsible for conducting research and gathering environmental data about the oceans, atmosphere, space, and the sun. The agency then applies this information to products and services that benefit all Americans. The NOAA line organizations that use space-derived environmental data include:

- National Weather Service;
- National Marine Fisheries Service;
- National Ocean Survey;
- Office of Oceanic and Atmospheric Research; and
- National Environmental Satellite, Data and Information Service.

## **SUMMARY**

For over four decades, the United States has led the world in the exploration and use of space. Our achievements in space have inspired a generation of Americans as well as the rest of the world. We maintain this leadership role by supporting a strong, stable, and balanced national space program that serves our goals in national security, foreign policy, economic growth, environmental stewardship, and scientific and technical excellence. Access to and use of space is central for preserving peace and protecting U.S. national security as well as civil and commercial interests. The U.S. military is committed to fulfilling national security objectives by integrating fully and effectively, the tremendous force enhancement potential of space-related assets into our national war-fighting capabilities. If the vast world of space systems is fully understood and effectively applied, space operations can have an impact on mission planning and execution, saving friendly lives and increasing weapon effectiveness.

# **CHAPTER 3**

## **THE SPACE ENVIRONMENT**

### **INTRODUCTION**

Knowledge of the space environment provides the understanding necessary to tactically optimize space assets. The space environment is hostile; there are continuous processes occurring in space that can alter the characteristics and change the performance of various space systems. In some cases, space weather events increase vulnerability to the loss of critical satellite functions or even entire systems. Increasing dependence on space-based systems to meet Naval operational objectives makes it imperative to have an understanding of the space environment.

In this chapter, we will review the different phenomena of the space environment known to impact humans as well as satellites. Additionally, we will look at satellite design guidelines and procedures that reduce these effects.

### **THE SUN**

The sun has the biggest effect on the space environment. Fueled by nuclear fusion, the sun combines or “fuses” 600 million tons of hydrogen each second. Two by-products of the fusion process that impact space systems are:

- Electromagnetic radiation
- Electrically charged particles.

### **ELECTROMAGNETIC RADIATION**

Electromagnetic radiation is energy radiated from the sun over the entire electromagnetic spectrum. Basically, it is an oscillating force field transmitted through space in the form of a transverse wave. The majority of this energy is characterized by visible light and heat which have minimal impact on space systems.

However, substantial amounts of electromagnetic radiation have the potential to adversely impact radar, communications, and space systems when they are enhanced and intensified by solar-geophysical phenomena or events. For example, the electrically charged particles of primary interest in the space environment are electrons and protons. These particles stream continuously from the sun to form what is called a “Solar Wind” (See Figure 3-1).

The solar wind travels at one million mph, carrying various particles from the sun. The interaction of the solar wind with the Earth's magnetic field produces a cavity in the interplanetary medium known as the Earth's Magnetosphere (See Figure 3-2). If the solar wind did not exist, we would have a decreasing dipole magnetic field extending into space from Earth indefinitely. However, the incoming solar gas compresses the field on the sunlit side of the Earth and sweeps magnetic field lines from near the poles back into a long tail. When the solar wind reaches Earth and interacts with its magnetic field, electric currents are formed that travel along magnetic field lines. Much like a magnet, the current is forced along the magnetic field lines down to the Polar Regions and excites the nitrogen and oxygen molecules in the ionosphere. This electrical energy is converted to light creating what is called the aurora, which is seen as a yellow-green light in the sky. It appears in many forms such as arcs with rays, bands, pulsation surfaces, and draperies. The aurora usually occurs in the northern latitudes of  $65^{\circ}$  to  $70^{\circ}$  and is known as the Aurora Borealis or Northern Lights. It also occurs in the Southern Hemisphere, where it is called the Aurora Australis.

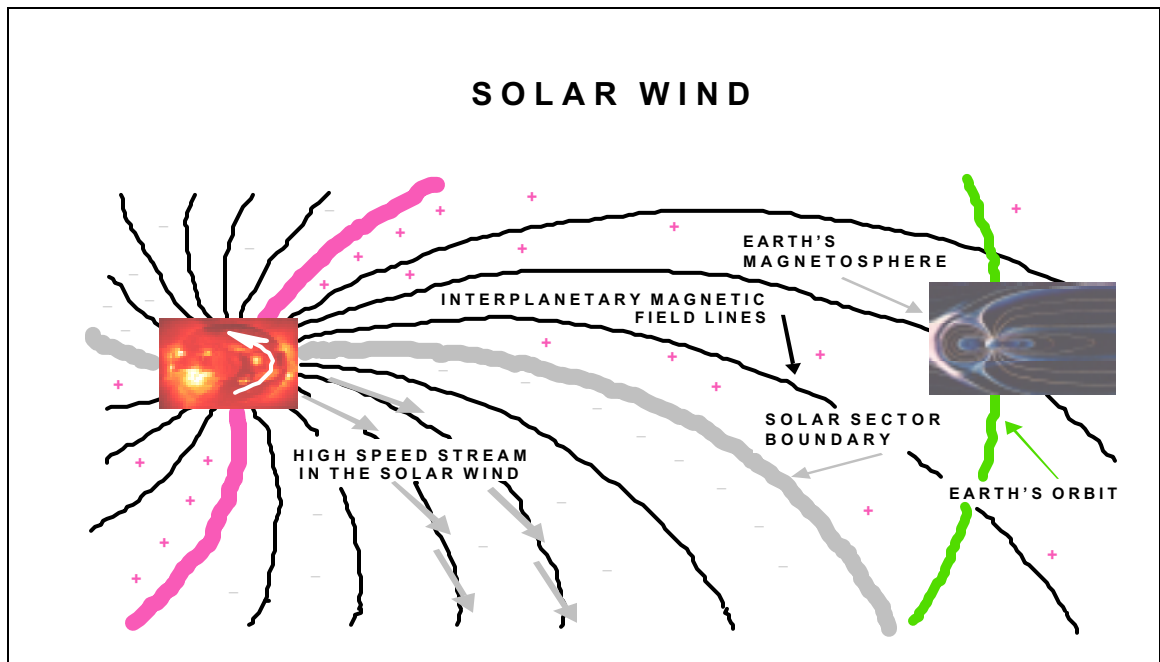


Figure 3-1. Solar Wind

This excited state of atmospheric molecules degrades radar performance in the auroral zones, including ballistic missile warning radar. It can also adversely affect satellites at altitudes to 600 miles, to include polar orbiting satellites.



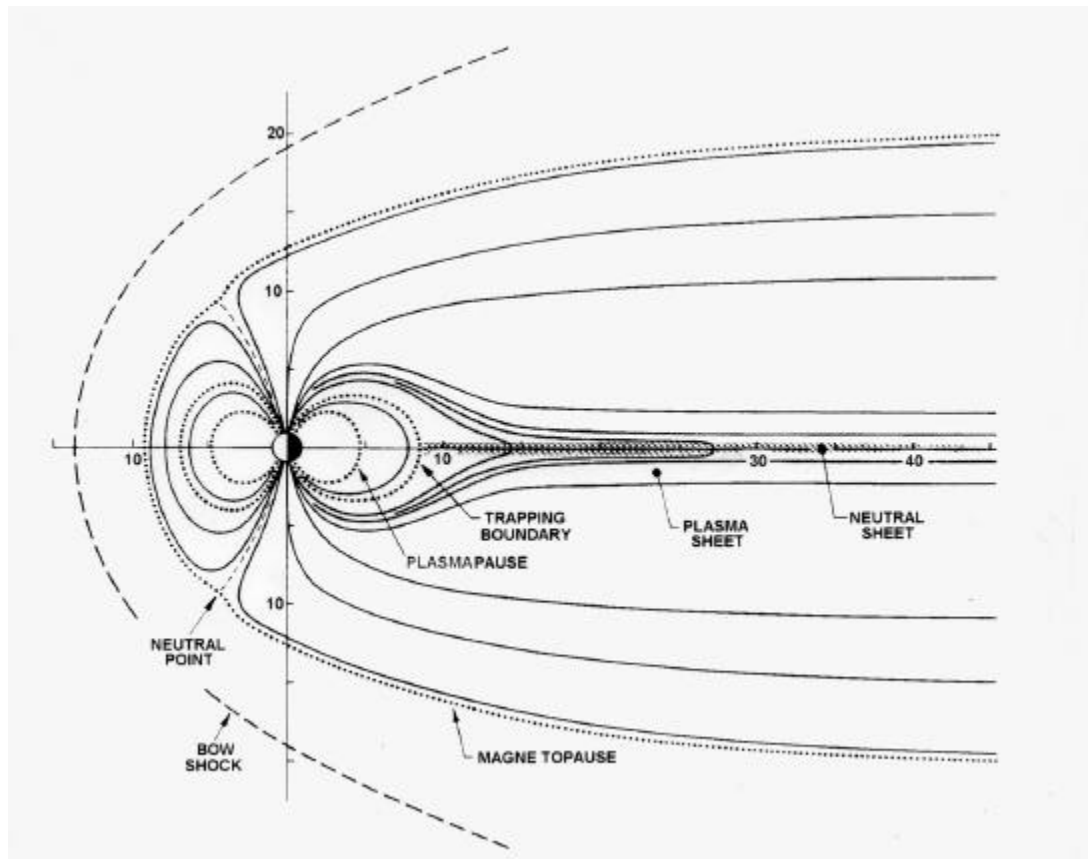


Figure 3-2. General Configuration of the Magnetosphere

In addition to the solar wind, the sun can also emit an explosive burst of electrically charged particles called a “solar flare.” Generally, the stronger the solar flare, the greater the intensity of a particle stream, and the more severe the impact of the event on space systems operating in that environment.

The main cause of solar activity is the solar flare which occurs within a relatively small region of the sun’s atmosphere. Flares are characterized by the stronger than normal X-ray, ultraviolet, optical and/or radio wave emissions. All of these wavelengths travel at the speed of light and reach the Earth in about eight minutes. Impacts are almost entirely limited to the daylight hemisphere since the rays do not penetrate or bend around the Earth’s surface. Normally, effects tend to last from only a few minutes up to about an hour or two although some lasting up to two days have been recorded.

Flares usually occur in the vicinity of “sunspots” or their pre-cursors, bright active regions called plage. Sunspots are transient dark spots on the surface of the sun. They appear as dark spots because they are cooler than the rest of the sun’s atmosphere. Individual sunspots have lifetimes that range from a few hours to several months, with most dissipating within several days of their appearance. The energy released by a flare is the energy stored in the intense, complex magnetic fields, which produce the sunspots. Some of the space systems that can be impacted by this radiation include communications satellites, navigation satellites, and radar. If the sun is in the field of view of a receiver and a burst is at the right frequency and intensity, Radio Frequency Interference (RFI) may occur. These electromagnetic impacts are almost entirely limited to the Earth’s sunlit hemisphere and occur simultaneously with the solar flare that caused them (See Figure 3-3).

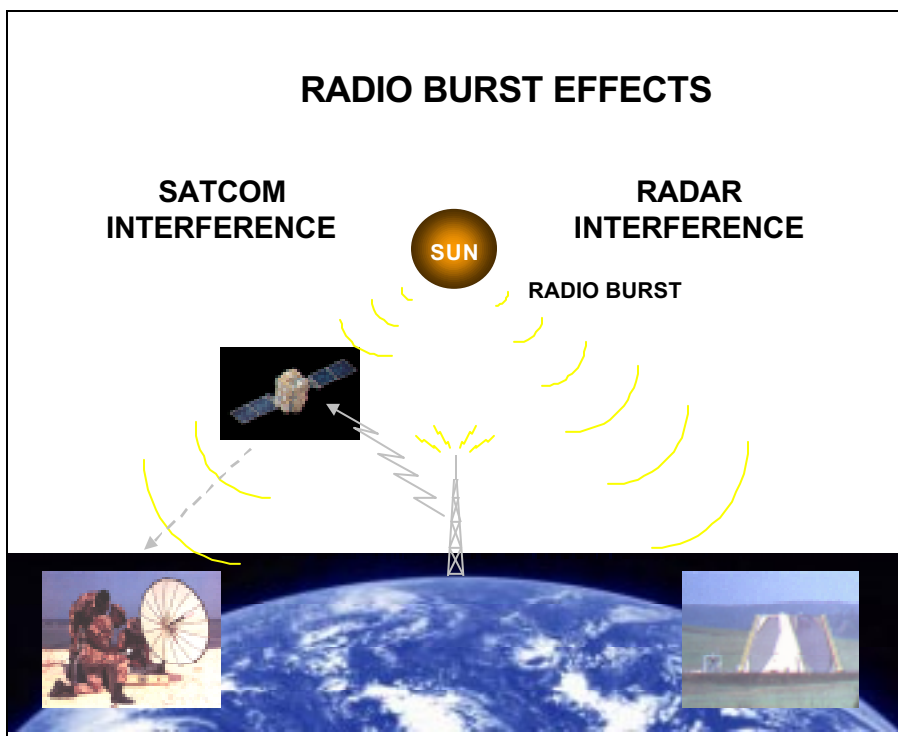


Figure 3-3. Radio Burst Effects

Solar activity is cyclic in nature, following a 11-year cycle which is called the Solar Cycle (See Figure 3-4). Generally there is a 4-year rise to a solar maximum, followed by a gradual 7-year decline to solar minimum.

Also related to this phenomena are geomagnetic storms. Geomagnetic storms are worldwide events that normally occur on Earth a day or two after a large solar flare erupts on the sun, and have an occurrence frequency that is directly related to the 11-year solar cycle. Geomagnetic storms are created when a “gust” of the solar wind compresses the Earth’s magnetic field and are recorded at geomagnetic observatories as a sudden change in the intensity of the local magnetic field. Since geomagnetic storms greatly hamper communications, it is fortunate that their effects usually die out within a few days.

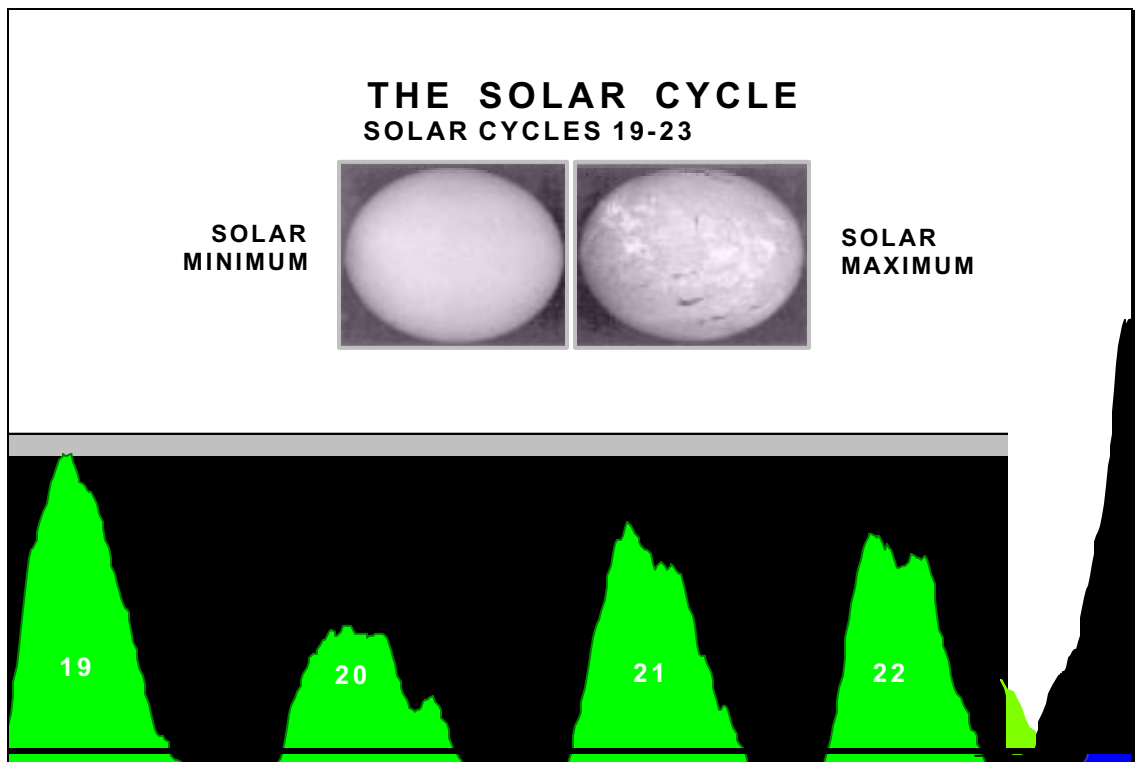


Figure 3-4. The Solar Cycle

Also, because the sun rotates, the emissions experienced in the near-Earth environment can vary as the sun’s active regions rotate around to the other side of the sun. A full rotation is completed about every 27 days, so active regions that “disappear” from our perspective on Earth, may appear a couple of weeks later as they move back into view.

### **ELECTRICALLY CHARGED PARTICLES**

Both low and high earth-orbiting spacecraft and satellites are subject to a number of environmental radiation hazards, such as direct physical damage and/or electrical upsets caused by charged particles (See Figure 3-5).

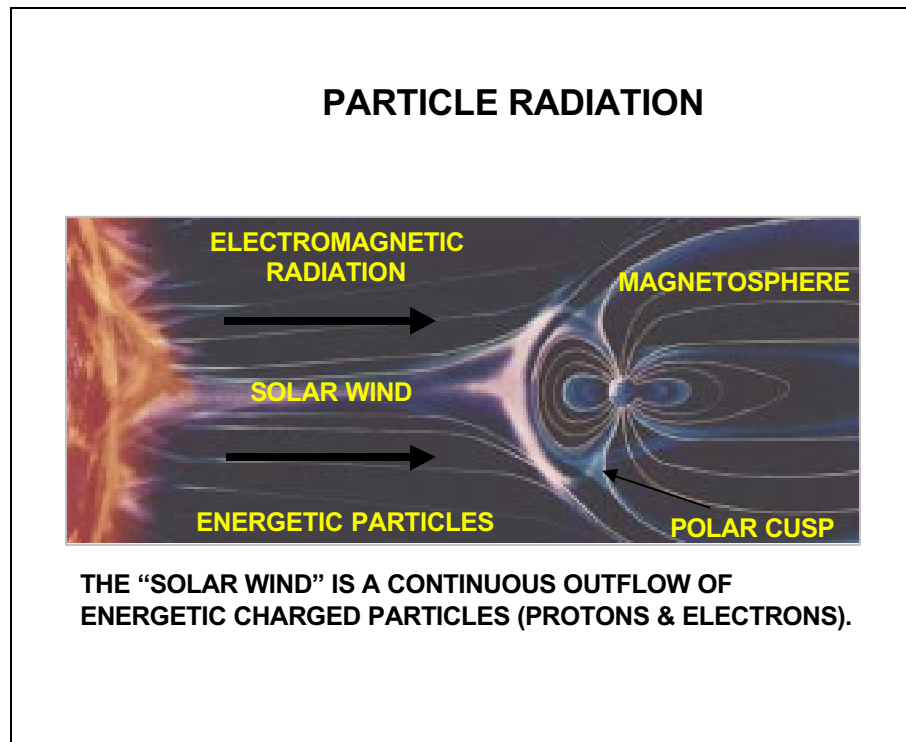


Figure 3-5. Particle Radiation

### High Energy Particles

These are primarily protons and electrons, but occasionally cosmic rays can reach the Earth within fifteen minutes to a few hours after the occurrence of a strong solar flare. The major impact of these particles is over the polar caps, where the protons have ready access to low altitudes through the funnel-like cusps that are created by the Earth's magnetic field lines that terminate at the North and South poles. These impacts can last from a few hours to several days depending on the intensity of the flare. Potential impacts include satellite disorientation, physical damage to spacecraft, false sensor readings, navigation errors, and absorption of HF radio signals.

Very high-energy protons or ions are capable of penetrating completely through a satellite. As they pass through, they will ionize particles deep inside the satellite. In fact, a single proton or cosmic ray can, by itself deposit enough charge to cause an electrical upset (circuit switch, spurious command or memory change or loss) or serious physical damage to on-board computers or other components. Hence these occurrences are called “single event upsets” (SEU) and are depicted in Figure 3-6. SEUs are very random, almost unpredictable events. They can occur at any time during the 11-year Solar Cycle. In fact, SEUs are actually most common near solar minimum, when the interplanetary magnetic field emanating from the sun is

weak and unable to provide the Earth much shielding from cosmic rays originating outside the Solar System.

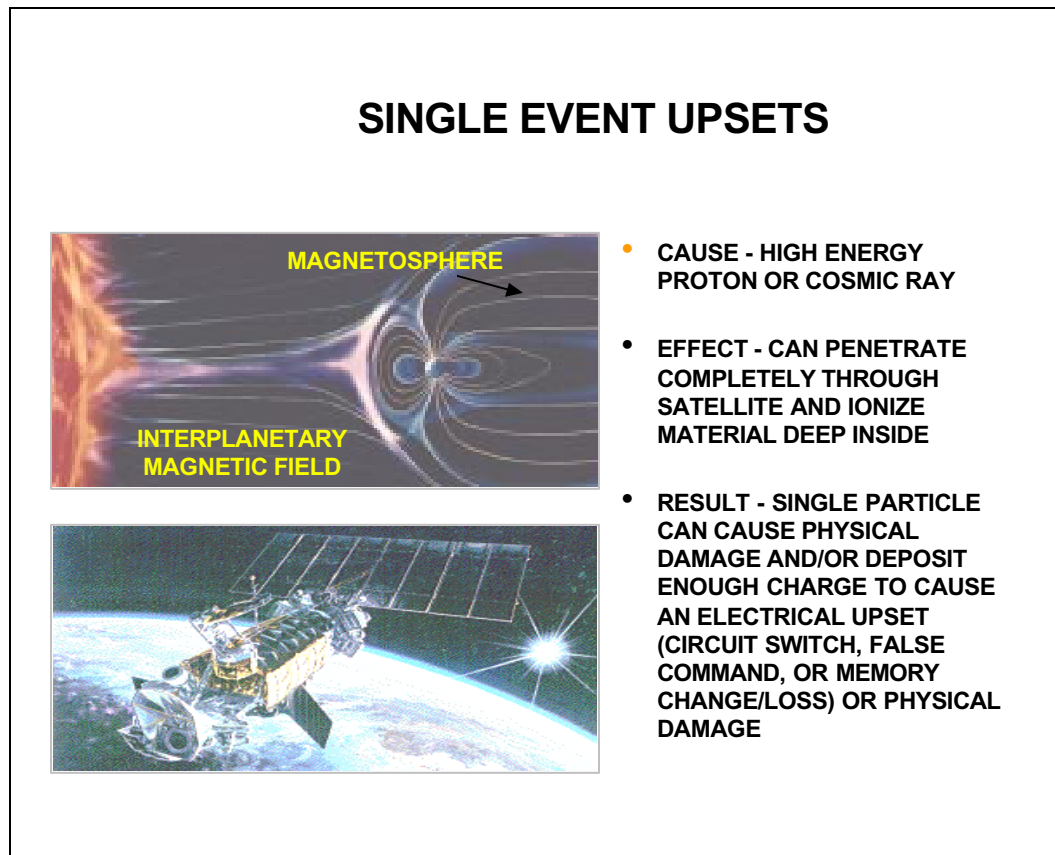


Figure 3-6. Single Event Upsets

Additionally, charged particles may be trapped in the Van Allen Radiation Belts. The Outer and Inner Van Allen Radiation Belts are two concentric, donut-shaped regions of stable, trapped charged particles that exist because the geomagnetic field near the Earth is strong and field lines are closed. The Inner Belt has a maximum proton density approximately 5,000 km above the Earth's surface and contains mostly high-energy protons produced by cosmic ray collisions with the Earth's upper atmosphere. The Outer Belt has a maximum proton density at an altitude ranging from 16,000 to 20,000 km and contains low to medium energy electrons and protons whose source is the influx of particles from the magneto-tail during geomagnetic storms. These radiation belts can have serious impact on satellite operations.

Communications satellites in "Geosynchronous" orbit (35,782 km or 22,235 statute miles altitude) suffer whenever the Van Allen belt moves inward or outward. Satellites in a semi-synchronous orbit such as GPS satellites suffer from a variable, high-density particle environment. Both orbits are particularly vulnerable to the directed motion of charged particles

that occurs during geomagnetic storms. Space vehicles in low circular orbit (125-130 miles) however, receive an insignificant amount of radiation from the Van Allen belts (See Figure 3-7).

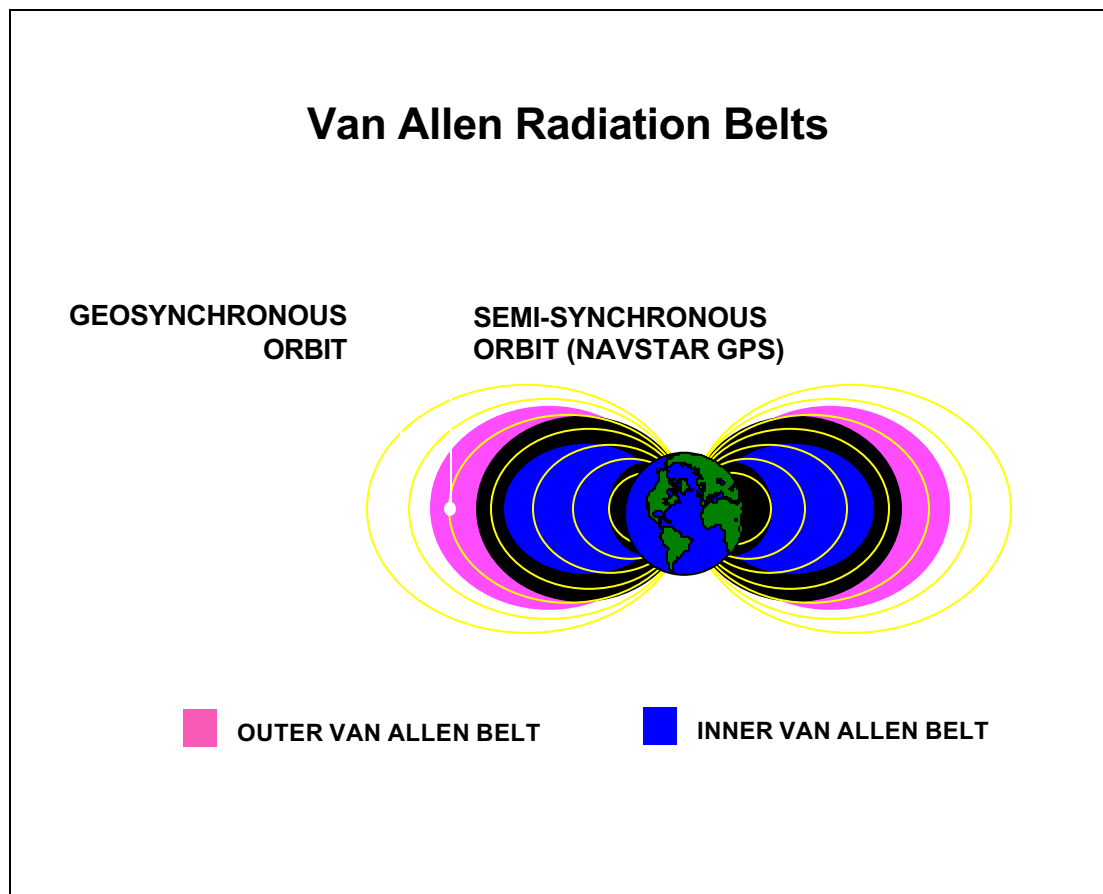


Figure 3-7. Van Allen Radiation Belts

An additional problem occurs when satellites rely on electro-optical sensors to maintain their orientation in space. These sensors lock onto certain patterns in the background stars and use them to achieve precise pointing accuracy. Such star sensors are vulnerable to cosmic rays and high-energy protons, which can produce flashes of light as they impact a sensor. The bright spot produced on the sensor may be falsely interpreted as a star. When computer software fails to find this false star in its star catalogue or incorrectly identifies it, the satellite can lose attitude lock with respect to the Earth. Directional communications antennae, sensors, and solar cell panels would then fail to see their intended targets. The result may be loss of communications with the satellite, loss of satellite power and, in extreme cases, loss of the satellite due to drained batteries (gradual star sensor degradation can also occur under constant radiation exposure). Disorientation occurs primarily when solar activity is high and on geosynchronous or polar-orbiting satellites (See Figure 3-8).

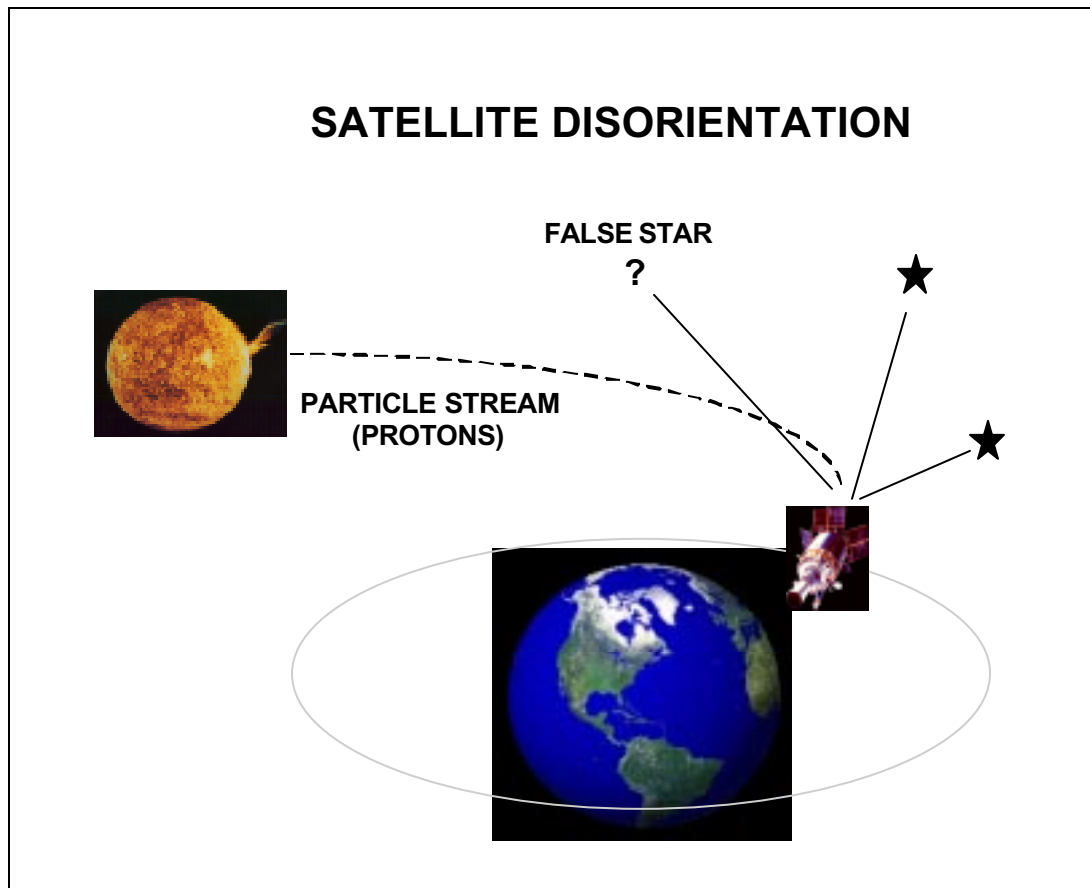


Figure 3-8. Satellite Disorientation from False Star Images

### Low to Medium Energy Particles

Streams of lower energy particles may arrive at the Earth about two to three days after a flare. These particles can occur at any time due to other non-flare solar activity. The radiated particles cause geomagnetic and ionospheric storms that can last from hours to several days. Most common impacts include spacecraft electrical charging, increased drag on low orbiting satellites, radar interference, space tracking errors, and radio wave propagation anomalies. These impacts are most frequently experienced in the night-side hemisphere of the Earth.

The intense ionospheric irregularities found in the Earth's auroral zones are also a cause of "scintillation" at high geomagnetic latitudes. Scintillation is the rapid, random variation in signal amplitude, phase and/or polarization caused by small scale irregularities in the electron density along a signal's path. The result is signal fading and data drop-outs on satellite command uplinks, data down-links or communications signals.

Scintillation tends to be a localized impact. Only if the signal path penetrates the ionospheric region where these small scale electron density irregularities are occurring will an impact be felt. Low altitude, nighttime links with geosynchronous communications satellites are particularly vulnerable to intermittent signal loss due to scintillation.

GPS satellites, which are located at semisynchronous altitude, are vulnerable to ionospheric scintillation. In particular, scintillation can cause a GPS receiver to lose signal lock with a particular satellite which may result in a potentially less accurate position fix.

Unlike other solar phenomena, there is no fielded network of ionospheric sensors capable of detecting real-time scintillation occurrences. Presently, space environmental forecasters are heavily dependent on their known association with other environmental phenomena.

Another source for space object positioning errors is that of atmospheric drag (See Figure 3-9) on low orbiting objects (less than 1,000-km altitude). Energy deposited in the Earth's upper atmosphere by charged particle bombardment heats the atmosphere, causing it to expand outward over a period of time. This produces more frictional drag on a satellite than expected and decreases its altitude while increasing its speed. Consequently, the satellite will be some distance below and ahead of its expected position when a ground radar or optical telescope attempts to locate it. Conversely, just the opposite conditions result when exceptionally calm solar and/or geomagnetic conditions cause less atmospheric drag than predicted and the object is higher and behind its expected location.

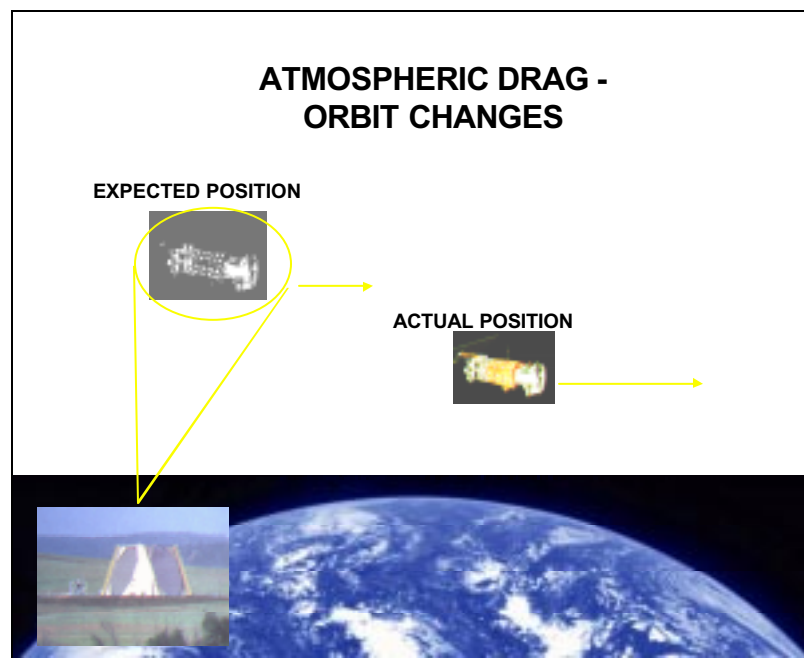


Figure 3-9. Atmospheric Drag on Satellites.



The consequences of atmospheric drag include:

- Inaccurate satellite locations which can hinder rapid acquisition of SATCOM links for commanding or data transmission;
- Costly orbit maintenance maneuvers may become necessary;
- De-orbit predictions may become unreliable.

An additional problem resulting from charged particle bombardment during a geomagnetic storm or proton event is potential damage to a launch vehicle or satellite. For example, an electric charge can be deposited on or inside the spacecraft. The electrostatic charge deposited may be discharged without serious impact by on-board electrical activity such as vehicle commanding. However, on occasion, this discharge has damaged payload circuitry.

## SUMMARY

Despite engineering efforts, satellites are still susceptible to solar events (See Figure 3-10). In fact, with newer microelectronics and their lower operating voltages, it will actually be easier to cause electrical upsets than on older, simpler vehicles. Furthermore, with the perceived lessening of the man-made nuclear threat, there has been a trend to build new satellites with less nuclear radiation hardening. This previous hardening had also protected the satellites from space environmental radiation hazards.

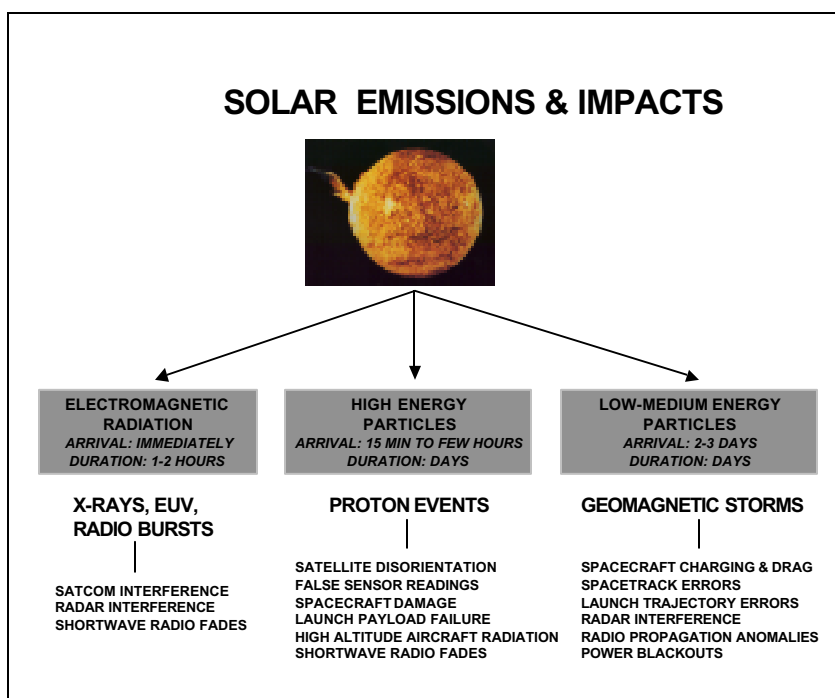


Figure 3-10. Solar Emissions and Impacts

## **EFFECTS ON SPACECRAFT AND MATERIALS**

During the design process, engineers analyze the hazards and risks that result directly from the effects of the natural environment, and attempt to minimize their impact on operations. The following provides an overview of the primary hazards found in the space environment, and highlight the factors that restrict the tactical use of satellites.

### **Upper Atmosphere Density Variations**

Density is the number of molecules per unit volume. Density of the atmosphere varies as a result of the balance between the gravitational force on molecules of different masses and the thermal energy of these molecules. A good approximation of this variation is that up to 100 miles altitude, air density decreases by a factor of 10 every 10 miles. Above 100 miles, the decrease is more exponential as the lighter elements (such as hydrogen and helium), become more predominant. Our atmosphere actually extends for thousands of miles above the Earth's surface, but in ever decreasing densities. Space, of course, provides an excellent vacuum, far better than that obtainable in any Earth laboratory. While this is an important advantage for many purposes, it can also cause serious problems.

Designers and operators must be careful about the problem of outgassing of volatiles from spacecraft hardware exposed to the vacuum. Escaping volatiles can condense on cooler external surfaces, or sometimes change the chemical properties of the substance from which they escaped. This condition can be a serious problem for optical instrumentation, where the deposition of even a very thin layer of outgassed material on lenses or mirrors can have adverse effects. Also, total outgassing takes a considerable amount of time (for some materials, upwards of 90 days has been recorded), so under normal conditions it should not be expected that a spacecraft would provide tactical information immediately following launch and orbit insertion.

Another problem associated with operating in a hard vacuum is that joints between spacecraft components in a vacuum tend to "cold weld" to each other preventing freedom of motion. In Earth's atmosphere, an extremely thin layer of air adheres to mostly all surfaces, acting as a lubricant between materials. Without this "natural" lubricant, substitutes must be developed and utilized. Common lubricants used routinely on Earth often boil away in space, so special substances must be employed in their place.

Some metals are stronger in the hard vacuum of space. If a crack forms in a metallic surface on the Earth where air surrounds the metal, air molecules immediately enter the crack and a chemical reaction with the metal occurs. In some instances the reaction causes a wedging action to take place and the crack is enlarged, thus weakening the metal. In a hard vacuum, this chemical reaction does not happen.

Long-term variations in the extreme ultraviolet (EUV) and soft X-ray emissions from the sun change the amount of upper atmospheric heating, which can affect the drag on LEO satellites. On a shorter time scale, plasma injections during geomagnetic disturbances are also an important source of upper atmospheric density variations. Although restricted to high latitudes, the atmospheric response to these storms can alter the orbits of polar-orbiting satellites, causing tracking and positioning errors.

## **Thermal Variations**

There are two ways in which the temperature of an object or particle can be classified:

- That which we can feel and measure with a thermometer because of its density (usually measured in degrees)
- That which is inherent within a particle due to its energy level.

Although space is relatively cold when measured with a thermometer, the various particles and plasma constituents may contain high equivalent temperatures in the thousands of degrees.

Spacecraft have limits of heat and cold which they can withstand for a specific period of time. In space, the temperature of an unprotected object will rise rapidly on the sunlit side, while simultaneously dropping to very low temperatures on the shaded side. Various types of materials are employed which reflect sunlight and insulate a spacecraft to maintain acceptable temperatures. Additionally, operational equipment generates heat that must be dissipated or dumped by some means. The only way to do this in a vacuum is by radiating the excess heat into space, which is a much less efficient process than doing so by convection.

## **Radiation**

Space radiation hazards can emanate from several sources:

- Solar flares
- Energetic solar particles
- Trapped particles
- Artificial events (such as a nuclear detonation in space)
- High energy galactic ions

Space radiation consists of protons ( $p^+$ ), electrons ( $e^-$ ), neutrons ( $n$ ), photons and HZE. Due to interactions in the solar system with radiation sources, radiation varies as a function of time and location. Although HZE has only an estimated 1-2% influence, it contributes 50% of the total radiation dosage received.

Proton radiation particles can travel at the speed of light and hence can reach Earth and LEO in 8 minutes. However, longer times are usually experienced because (1) the particles diffuse out from the sun; (2) electrically charged particles spiral around the magnetic fields (See Figure 3-11) instead of traveling linearly; (3) particles are disturbed by shock waves.

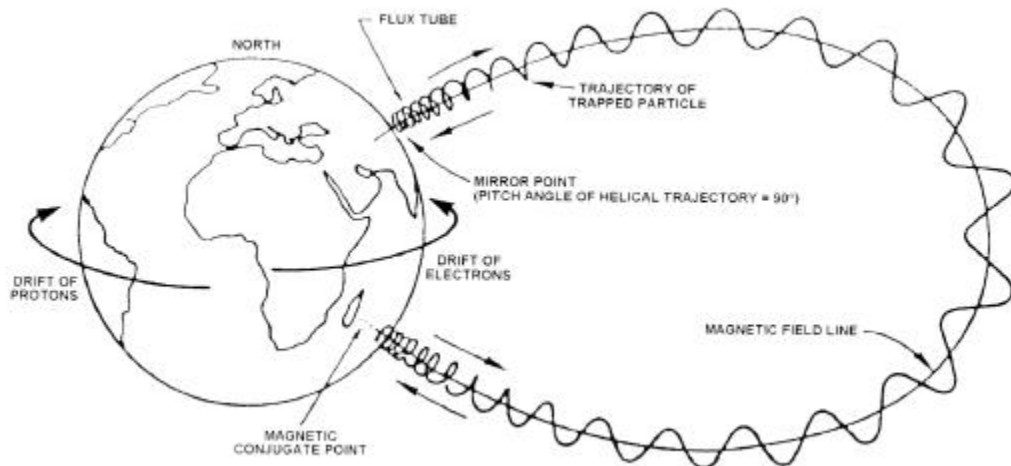


Figure 3-11. Typical path of charged particles in a magnetic field.

The Earth is protected from space radiation by both its strong geomagnetic field and the depth of its atmosphere. At some locations, such as the poles, the magnetic protection is minimum yet the atmospheric protection is sufficient. Satellites in LEO and low inclination are generally shielded by the magnetic field, not by the atmosphere. However, due to the structure of the magnetic field and ionic trapping effects, there are areas where the magnetic field collects particles rather than acts as a shield.

On hardware, especially solid state electronic devices operating in space, SCR can generate enough electrons to change the state of a circuit element, or produce a "bit flip" (changes the electronic state of a 1 to a 0 in computer memory), resulting in software errors or permanent damage. Radiation can also cause interference such as noise, or impact damage leading to degraded operation or destruction of the equipment.

Also, as we have seen, the near-Earth space environment is not a total vacuum. This means that the spacecraft is constantly being bombarded by atmospheric particles moving at relatively fast velocities. Some of these particles are the monatomic oxygen atoms (O) created by photo-dissociation. When these atoms strike a satellite, being a highly reactive element, they tend to combine with the spacecraft materials and create potentially damaging corrosion. The effects of this corrosion are quite small, but could build up over long periods of time in space, especially on the exposed surfaces in the direction of flight.

Sensors used in spacecraft are usually very sensitive to particular wavelengths of energy. Direct exposure to solar radiation may result in unwanted signal reception and possible sensor damage. If the purpose of a system is to pick up the weak radiation of a far away planet or star, and the sensor happens to inadvertently look in the direction of the sun (or a reflection of some of its energy), the desired signals may be obscured in the sun's radiation and the sensor itself may be damaged. Additionally, the sensors themselves must be protected from the general effects of the space environment described above, or performance may be adversely affected.

### **Spacecraft Charging**

The term spacecraft charging refers to the variation in the electrostatic potential of a spacecraft surface with respect to the surrounding plasma, where tens of thousands of volts can develop between the two. This can occur in LEO, as well as in deep space and can result in structural and electrical equipment damage. Although the build-up of static charge may affect certain spacecraft sensors, the real danger lies in any possible resulting discharge or arcing because structural damage is a real possibility. Even weak discharges may bring about spurious electronic switching, the breakdown of thermal coatings, and solar cell and optical sensor degradation.

The major sources of charging that change a spacecraft's potential are as follows:

- Electrons and ions from the surrounding thermal plasma
- High energy particles
- Secondaries produced as a result of external particle impacts
- Photoelectrons
- Secondaries from internal particle sources, such as radioisotope thermal generators (RTGs)

Which of these sources is most important depends on the region of space involved. In near Earth space, thermal electron and photoelectron fluxes predominate. These two sources work against each other in that captured thermal electrons will charge a spacecraft negatively while ejected photoelectrons will leave behind a positively charged spacecraft. These effects are more pronounced for spacecraft having odd shaped exteriors with protuberances, depressions, holes, etc. Sometimes the surface potential varies considerably from one part of a spacecraft surface to another.

Because there are so many spacecraft at geosynchronous altitude, spacecraft charging has been studied there in particular. Space vehicles at this altitude are susceptible to plasma injection events that accompany geomagnetic disturbances and substorms. Such events may occur several times per day even on quiet days, and may produce a ten-fold increase in ion densities and a thousand-fold increase in electron densities at geosynchronous orbit. Such charging is most likely near local midnight (spacecraft time) and not during daytime. Because of

the anomalous behavior of some military spacecraft at geosynchronous orbit, the USAF carried out a research program to investigate the phenomenon of spacecraft charging at high altitude (SCATHA). The results demonstrated the concept of active discharging by a plasma gun to reduce spacecraft potentials safely when necessary, and provided a computer code for calculating satellite surface potentials. SCATHA developed a method for modeling active charging/discharging and created an atlas of the geosynchronous environment.

## **MACROSCOPIC BODIES**

Macroscopic bodies range in size from small micrometeoroid particles to man-made objects, large meteoroids, and satellite debris. When compared to natural space debris, man-made debris usually travels at slower orbital velocities. Natural space bodies, on the other hand, can enter and cross through the path of the Earth and thus have considerably higher relative velocities and a correspondingly higher destructive impact potential.

### **Meteoroids and Micrometeoroids**

In addition to the ionized particles of the solar wind and magnetic fields, interplanetary space also contains a considerable amount of solid matter, most of which is in the form of small particles called interplanetary dust. The entire assortment of all the solid pieces in the interplanetary space is called the *meteoritic complex*.

The term meteoroid refers to a particle while it is moving in space. When a meteoroid enters the atmosphere and begins to glow, it is called a meteor. If the same particle survives the journey through the atmosphere and hits the Earth, the remnant is called a meteorite. A few meteorites are large (the largest ever found weighed about 50 tons and there is crater evidence for even larger ones), but most are very small and are called micrometeorites.

Meteoroids move with speeds between about 30,000 mph to 160,000 mph. At these speeds the impact of a large meteoroid on a satellite would be catastrophic. Impacts between micrometeoroids and a satellite would not necessarily be catastrophic, but could erode the satellite's surface, a potentially serious hazard to optical surfaces or to surfaces used for thermal control or solar power generation.

Because of the conjectural nature of the process, meteoroids were frequently blamed when early satellites ceased to function. A number of satellites, including Explorers 16 and 23 and the three satellites in the Pegasus series, have been used to study the problem. The present conclusion is that the probability of a satellite being hit catastrophically by a large meteoroid is very small, but the probability of its being hit by many small micrometeoroids is quite large.

## **HARDNESS AND SURVIVABILITY REQUIREMENTS**

Survivability is the ability of a space system to perform its intended function after being exposed to a stressing environment created by an enemy or hostile agent. Hardness is an attribute defining the environmental stress level which a space system can survive.

A military space system or commercial satellite must be survivable if we will need its services in times of high stress, such as a nuclear war. To do this, we must understand what may cause the system to malfunction and design it to protect against failures. Survivability requirements include identifying the environments and their intensities and, in most cases, designing the space system so it will continue to perform its intended function for a certain time after exposure.

Commercial or scientific satellites usually do not need to be survivable, but planners must be aware that an unhardened satellite may stop operating after even very distant nuclear explosions. A slight hardening of satellites can make them much more survivable.

It is important to consider survivability from the outset of mission design. For example, if the satellite can function within a range of orbit altitudes, the highest of these is both the hardest to attack and the most expensive to reach. We should consider the system's survival in each of its life cycles phases, including concept definition, engineering design and development, and operations in orbit. Historically, we have not hardened launch systems because of cost and weight, as well as undefined need. The main threats against space systems are nuclear weapons, including directed energy designs such as X-ray lasers; ground – and space-based radio frequency (microwave) weapons; homing kinetic energy weapons; and beam weapons using neutral atomic particles. We may use several approaches to make a system survivable, with hardening of the satellite as a key element.

## **THE NUCLEAR WEAPONS ENVIRONMENT AND ITS EFFECT ON SPACE SYSTEMS**

Nuclear weapons pose the most severe threat to spacecraft or space systems. The yield, or explosive power, and accuracy of delivery are such that if a nuclear weapon directly attacks a spacecraft, ground station, or any other node of a space system, the node will be destroyed. Nuclear weapon yields can range from a few tons to many megatons of TNT equivalent (one kiloton of TNT is defined to be  $10^{12}$  calories). Future nuclear exchanges could use yields of a few hundred kilotons to a few megatons, depending on the purpose of the specific attack and the weapon's delivery accuracy. Accurate delivery of low yields will achieve the desired kill probability, whereas less accurate delivery requires higher yields. Approximately 80 percent of the energy from a nuclear weapon detonated in space appears in the form of X-rays. Other important effects include small amounts of gamma rays and neutrons, as well as small fractions in residual radioactivity and kinetic energy of bomb debris.

## **SPACE ENVIRONMENTAL SUPPORT**

### **The 55th Space Weather Squadron (55SWXS)**

55SWXS is DoD's only space environmental analysis and forecasting facility. The squadron is a 24-hour support operation providing tailored space environmental products and services to DoD and national program customers. The 55SWXS headquarters is at Schreiver AFB, Colorado and operates several Geographically Separated Units (GSUs) to monitor the sun. Known as the Solar Electro-Optical Network (SEON), it is the only network in the world dedicated to observing the sun at optical and radio wavelengths in real time.

### **Mission**

55SWXS provides space environmental support for worldwide operations. The squadron gathers and processes space environmental data from ground and space-based sensor networks, analyzes and models the space environment, forecasts solar and space environmental phenomena, and provides alerts, warnings and assessments for operational impacts to Air Force and other DoD agencies. Support to customers can be provided at the unclassified, collateral and Sensitive Compartmented Information (SCI) levels. Systems supported include satellite vehicle and payload operations, ground and satellite-based communications, navigation, surveillance, and weapon system radar, as well as high-altitude reconnaissance aircraft and the Space Shuttle.

55SWXS products fall into one of four categories:

- **Parameter Observations:** The 55SWXS monitors solar activity through the data received from SEON, other ground-based ionospheric sounder networks, and satellite-based sensors. Critical parameters from this data are used to optimize tailored environmental models used in specifying satellite locations and enhancing HF and satellite communication links, as well as radar and satellite tracking correction and calibration.
- **Analysis:** Near-Real Time and Post Analysis. This category gives system operators, engineers, and decision makers expert analyses of the role the space environment plays in system anomalies. This provides quicker resolution of anomalies, reducing system down-time, and saving time searching for other causes.
- **Forecasts:** 24-Hours, days, months and years. All portions of the radio spectrum are subject to variability in the ionosphere. The 55SWXS provides predications of critical parameters for optimizing HF and satellite communication operations and planning, satellite drag predication, and radar and satellite signal correction.



- Warnings: Navigation systems are influenced by energetic proton flux into the polar caps as well as geomagnetic activity. Also, energetic protons pose a significant health hazard to high-altitude reconnaissance aircraft pilots and astronauts operating in the space environment. Satellite systems in certain orbits can perform anomalously or be damaged during solar flare induced particle storms. The squadron provides situational awareness products, potential systems effects, and aids in system anomaly resolution in support of radar, satellite vehicle, and payload operations.

## **MAN-MADE DEBRIS**

In the short time that man has been able to place objects in space, he has already created a serious situation with the pollution of the environment consisting of the debris created by launch vehicles and spacecraft operations. At present U.S. Space Command has counted approximately 10,000 artificial space objects in near Earth vicinity, where the probability of a spacecraft collision with one of these objects is greater than that of a collision with a natural meteoroid.

## **SUMMARY**

The sun shapes the characteristics of terrestrial space, causing phenomena that can significantly affect operation of Earth-orbiting satellites. In some situations, these phenomena can be predicted and negative effects may be avoided. However, present technology does not allow us to circumvent all negative effects caused by the space environment. Until we better understand the space environment we will be at the mercy of this harsh operating medium.



## **CHAPTER 4**

# **ORBITAL MECHANICS**

**Note:** A film entitled "Spaceflight: The Application of Orbital Mechanics," jointly produced by the Naval Space Command and the National Aeronautics and Space Administration (NASA), is available to supplement the following text on Orbital Mechanics. This 35-minute film uses state-of-the-art computer graphics to clearly portray the fundamentals of orbital mechanics in a simple, understandable manner.

The film is available in all formats (3/4", VHS, Beta) and can be acquired through the Fleet Audiovisual Libraries. It is also available at no cost through the Defense Audiovisual Information System (Product Identification Number 804859DN).

### **INTRODUCTION**

In order to speak and understand the "space language" being introduced into Naval operations, a basic knowledge of the fundamentals of orbital mechanics is essential. Consequently, this chapter is designed to provide you with a layman's understanding of the field of Celestial or Orbital Mechanics – a basic explanation of the way objects move in orbit around the earth. A short section on the history of celestial mechanics is included to give you an appreciation of the permanency and complexity of this, the most basic science governing our operations in space.

The study of trajectories and the orbits of vehicles in space is not a new science. However, the application of the concepts of celestial mechanics to man-made vehicles is less than a century old. To differentiate, celestial mechanics is mainly concerned with the determination of trajectories and orbits of the stars and planets in space. Orbital mechanics uses the same procedures and techniques, but applies them toward the computation of orbits and trajectories of man-made objects in outer space. (Astronomers say "celestial mechanics," people in the space operations business say "orbital mechanics.")

### **EARLY ASTRONOMY**

To fully understand the concepts and laws associated with orbital mechanics, it is necessary to go back to the very beginning of civilization. It is impossible to state with certainty when the earliest quantitative observations of the heavenly bodies were made; however, it is known that many early civilizations recognized the pattern and regularity of the motions of the stars and the planets. Some made an effort to track and predict celestial events. In particular, the invention of the calendar required an elementary knowledge of astronomy.

The Chinese had a working calendar at least as early as the fourteenth century B.C. They also maintained accurate records of comets, meteor showers, meteorites, and other phenomena. Egyptian astronomers were able to roughly predict the flooding of the Nile River each year near the time when the star Sirius could be seen rising in the dawn sky just before the sun. The Bronze age people in Northwestern Europe built many monuments such as Stonehenge, which was certainly used as a crude calendar.

One of the earliest known attempts to describe the location of the planets, Sun, Moon, and their motions with respect to each other was by Pythagoras. He assumed that the Earth was stationary at the center of a system comprised of the seven known moving objects visible to the unaided eye—the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn. Pythagoras theorized that all revolved about the Earth in complex spherical orbits. This was known as the geocentric theory.

Aristotle (384-322 B.C.), one of the most famous of Greek philosophers, understood such phenomena as the phases of the Moon and eclipses. Aristotle considered the theory that the apparent daily motion of the sky could be explained by a hypothesis of the rotation of either the Earth or of the celestial sphere. Perhaps most importantly though, Aristotle considered the possibility that the Earth revolves around the Sun, instead of the more popular idea that the Earth was the center of the universe.

Aristarchus of Samos (310-230 B.C.), another famous Greek astronomer, was the first to profess a belief in the heliocentric theory—that the Earth moves about the Sun. He also believed that the stars must be extremely distant to account for the fact that their apparent positions in the sky remain the same all year long. However, because Aristarchus' ideas were too revolutionary, they were rejected, and the geocentric theory continued to be accepted for centuries.

About A.D. 140, Claudius Ptolemy amplified the geocentric theory by developing an elaborate geometrical representation of the solar system, which predicted the apparent motion of the planets with considerable accuracy. According to his theory, the planets revolve about imaginary planets, which in turn revolve around the Earth. Ptolemy's hypothesis, with some later modifications, was accepted as absolute authority throughout the Middle Ages.

## **MODERN ASTRONOMY**

It was not until some 1800 years after Aristarchus had first proposed the heliocentric theory, that a Polish monk named Nicolaus Copernicus (1473-1543) published a book in defense of the heliocentric system. Copernicus postulated that the Earth was one of the six (then known) planets that revolve around the Sun. Starting nearest the Sun, he ordered the planets Mercury, Venus, Earth, Mars, Jupiter, and Saturn. He further deduced that the closer a planet is to the Sun, the greater its orbital speed. Thus, the retrograde (or, backward) motion of Mars, Jupiter, and Saturn was easily explained. He also calculated the approximate scale of the

solar system. Contrary to what has been a popular belief, Copernicus did not prove that the Earth revolves about the Sun.

A Danish astronomer, Tycho Brahe (1546-1601), established an astronomical observatory in 1576, where for 20 years he carried out the most complete and accurate astronomical observations made up to that time. In 1600 Brahe was joined by a young German mathematician named Johannes Kepler (1571-1630). Brahe put Kepler, an early convert to the heliocentric theory, to work on finding a satisfactory theory of planetary motion.

## **LAWS OF MOTION**

Kepler's most detailed study was of Mars, for which Brahe's observational data was the most extensive. For 10 years he attempted to fit combinations of circular motion to the observed motion of Mars. Finally, Kepler tried to represent the orbit of Mars with an oval and soon discovered that the orbit could be fitted by a curve known as an ellipse.

### **KEPLER'S LAWS OF PLANETARY MOTION**

Kepler found that Mars has an orbit that is an ellipse, with the Sun at one focus (the other focus of the ellipse is empty, an unoccupied point in space). Kepler generalized that what is true for Mars must be true for the other planets as well. This generalization has become known as Kepler's First Law of Planetary Motion.

#### **Kepler's First Law of Planetary Motion (Law of Ellipses)**

Each planet moves in an elliptical orbit with the Sun at one focus and the other focus empty. This law also applies to man-made objects orbiting the Earth (i.e., satellites). The orbit of each satellite is an ellipse with the center of the Earth at one focus and the other focus unoccupied. This law simply implies that the purpose of the occupied focus (i.e., the Earth) is to provide gravitational attraction to the satellite to keep the satellite in its elliptical orbit (see Figure 4-1).

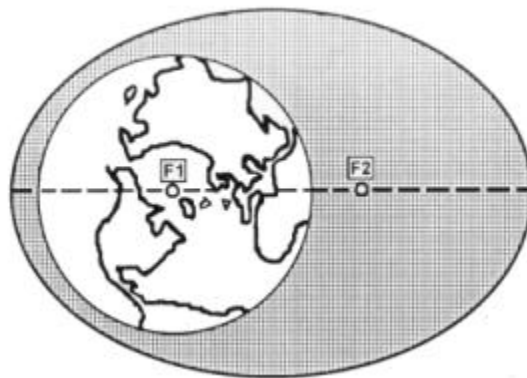


Figure 4-1. Kepler's 1st Law applied to an Earth satellite.

### Kepler's Second Law of Planetary Motion (Law of Areas)

The line joining a planet to the Sun sweeps over equal areas in equal time intervals. As applied to an Earth-orbiting satellite, the line joining it to the Earth sweeps over equal areas in equal periods of time (see Figure 4-2). This law implies that the speed of a satellite changes depending on its distance from its gravitational attraction source, the center of the Earth. A satellite's speed is greatest at the point in the orbit closest to the Earth, and is slowest at the point farthest from the Earth. If a satellite is traveling in a circular orbit, then the speed of the satellite is constant.

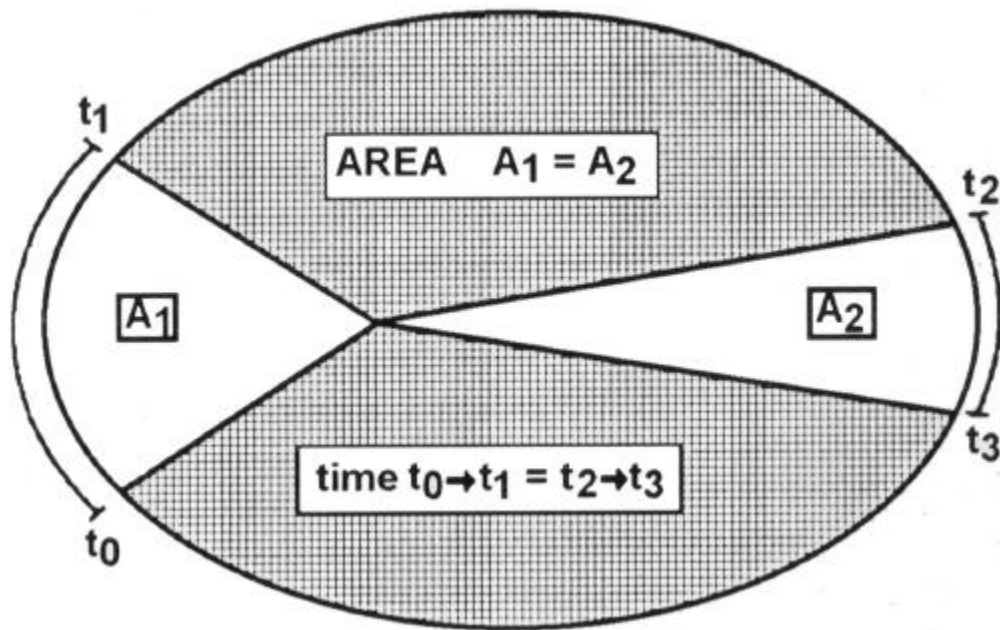


Figure 4-2. Kepler's 2nd Law.

It is important to understand that the orbit followed by a satellite is not dependent on its mass. A large, heavy satellite could be in the same orbit with a small, light satellite with each sweeping out equal areas in equal periods of time.

### Kepler's Third Law of Planetary Motion (Law of Harmonics)

For any planet, the square of its period of revolution about the Sun is directly proportional to the cube of its mean distance from the Sun. When applied to earth satellites, this

law explains that the farther a satellite is from the Earth, the longer it will take to complete its orbit, the greater the distance it will travel, and the slower its average speed.

This law is expressed as follows:

$$p^2/d^3 = K$$

where  $p$  is the period

$d$  is the distance

$K$  is a constant with the same value for all satellites

## **GALILEO GALILEI**

An Italian mathematician, Galileo Galilei (1564-1642), contributed greatly to the understanding of the behavior of objects at rest or in motion. In addition to being the first person to develop and use a telescope, he accumulated a great deal of evidence in support of the heliocentric theory. In 1632, he published the "Dialogue of the Two Great World Systems," which examined all arguments for and against the heliocentric theory.

## **NEWTON'S LAWS OF MOTION AND UNIVERSAL GRAVITATION**

While declaring his three laws of planetary motion, Kepler deduced that a force from the Sun pulled on the planets, but he did not determine the mathematical nature of this force. Galileo discovered some of the basic laws governing the behavior of physical objects. Sir Isaac Newton (1643-1727), regarded as the father of classical mechanics, drew upon the work of both Kepler and Galileo to formulate the Law of Universal Gravitation and the three Laws of Motion. While Kepler's laws provided a conceptual model of orbital motion, Newton's laws provided the foundation for the mathematical description of orbits and why a satellite remains in orbit.

### **Newton's First Law of Motion (Law of Inertia)**

A body in motion will keep moving at the same speed and in the same direction unless acted upon by an external force. This explains why a satellite moves in a curved path around the Earth, because the Earth's gravitational pull acts as an external force on it.

### **Newton's Second Law of Motion (Law of Momentum)**

If the sum of forces acting on an object is not zero, the object will have an acceleration proportional to the magnitude and in the direction of the net force. This provides some of the explanation for changes in a satellite's orbit due to external forces other than the Earth's gravity, and the need to adjust a satellite's orbit.



### **Newton's Third Law of Motion (Law of Action & Reaction)**

For every action, there is an equal and opposite reaction. This law explains how a satellite gets into orbit.

### **Newton's Law of Universal Gravitation**

Any two objects in the universe attract each other with a force directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. Mathematically, this law is expressed as follows:

$$F = G(m_1 * m_2) / d^2 \quad \text{where } F \text{ is the force acting between the bodies}$$

$G$  is the universal constant of gravitation

$m$  is the mass of a body, and

$d$  is the distance between the bodies

Simply stated, the more massive the objects, or the closer they are together, the greater the gravitational pull between them.

## **ORBITAL PARAMETERS**

To better understand the operational application of satellites, you should become familiar with the fundamental terms and relationships associated with satellite orbits.

### **ORBITAL INSERTION**

To illustrate how a satellite is placed into orbit, refer to Figure 4-3. Imagine someone standing atop a tall mountain and throwing a ball horizontally. Not considering atmospheric friction, the Earth's rotation, or any other force except gravity, the path of the ball will curve downward due to gravity and it will strike the Earth (Path A). Now, if that person fires a gun horizontally, the bullet will obviously go farther than the ball, but it will still be pulled down to the Earth (Path B). However, if a projectile is fired horizontally at a very high speed, approximately 17,500 miles per hour, the curvature of its path due to gravity will match the curvature of the Earth below it. The projectile will then continue to "fall" around the Earth just as fast as the Earth curves away from the projectile, and become an Earth-orbiting satellite (Path C).

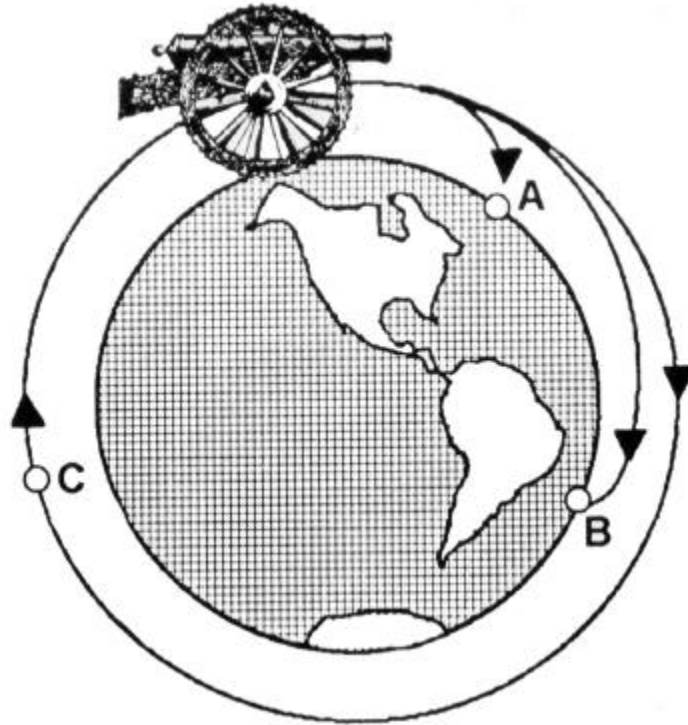


Figure 4-3. Orbital insertion.

For an object to achieve orbit, sufficient energy must be provided so that the path does not intersect the surface of the Earth. However, the object cannot be given too much energy or it will escape the effects of the Earth's gravity. The following three conditions are required to place an object in orbit:

- The object must be put above most of the Earth's atmosphere (approximately 60 miles high) to negate the effects of atmospheric friction
- The object must be imparted with a speed of approximately 17,500 miles per hour within about 200 miles of the Earth's surface
- The object's speed must be in a direction parallel to the surface of the Earth.

### **POSSIBLE SATELLITE ORBITS**

Suppose that an object is boosted to an altitude of approximately 200 miles above the Earth's surface, then turned so that it is horizontal to the Earth, and finally provided with a forward horizontal motion. The object will enter into an orbit the size and shape of which depends on the exact direction and speed of the object at "burnout" (when thrusting terminates). If the object is moving horizontally to the earth, the possible types of orbits it can enter are depicted in Figure 4-4.

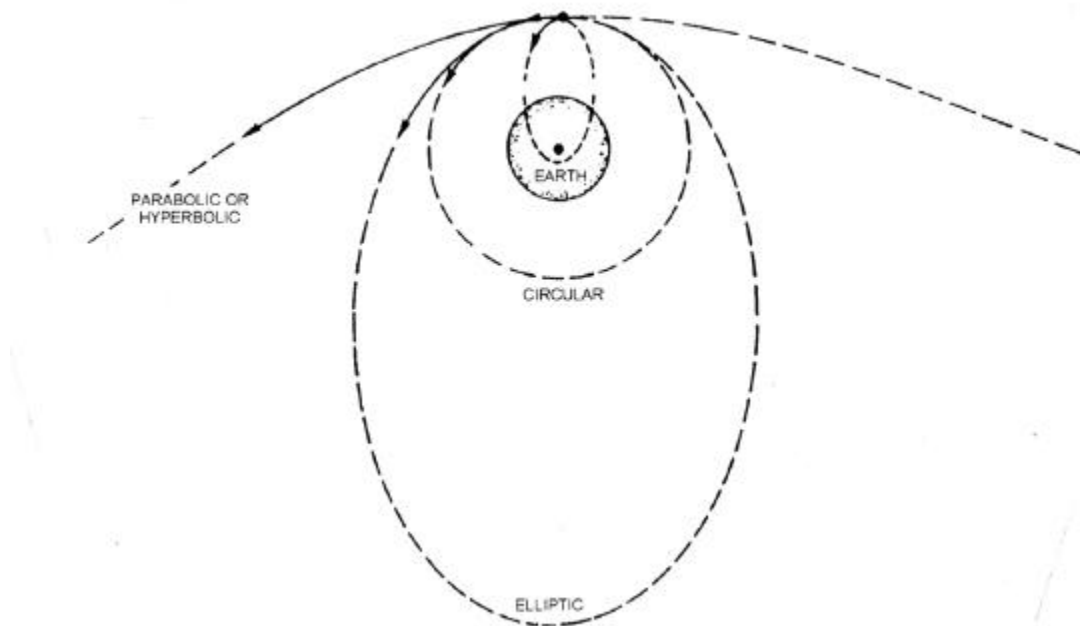


Figure 4-4. Possible satellite orbits.

If the object's burnout velocity is slightly greater than that required for a perfect circular orbit, the resulting orbit will be elliptical with the center of the Earth at one focus. The point farthest from the center of the Earth will be the point of burnout.

If the burnout velocity is substantially below the circular-orbit velocity requirement, the object will strike the Earth's surface. If the burnout velocity is just slightly below the circular-orbit velocity, the object may barely clear the Earth's surface, but atmospheric drag would soon cause it to slow down below the required orbital velocity and it will strike the Earth.

If the burnout velocity is exactly the circular-orbit velocity requirement, a circular orbit results (in practical situations, this is nearly impossible to achieve). Burnout velocities equal to or greater than the escape velocity from the Earth's gravitational field result in parabolic or hyperbolic orbital paths. At these velocities, satellites will escape the gravitational pull of the Earth and never return.

## ORBITAL TERMS AND ELEMENTS

When an object's burnout velocity results in an elliptical orbit, a point on the orbit farthest from the center of the Earth is referred to as apogee (apogee – “away”). The point closest to the center of the Earth will be halfway around the orbit and is called perigee (see Figure 4-5). Apogee and perigee are always 1/2 revolution apart. For a circular orbit, apogee and perigee altitude are equal.

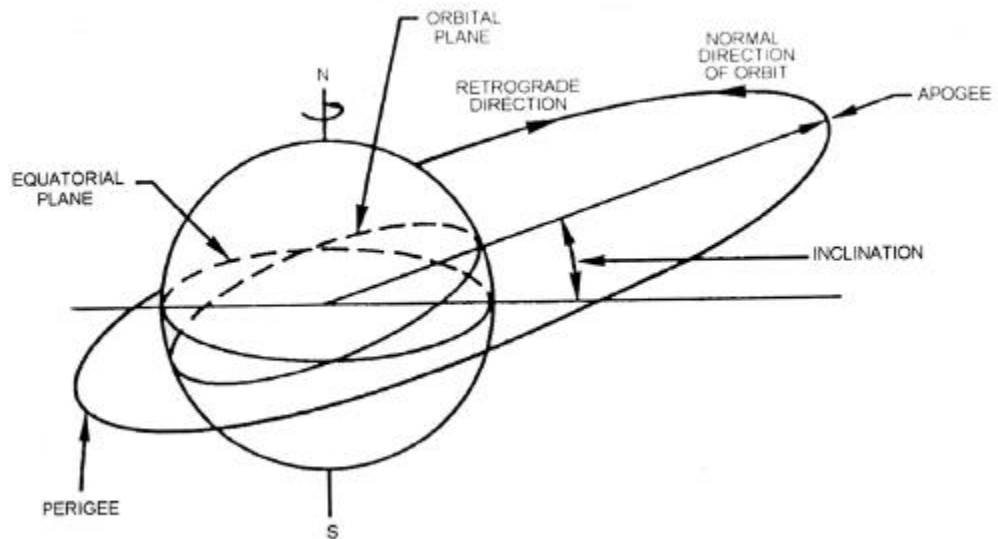


Figure 4-5. Orbital parameters.

### Orbital Elements

Six parameters, often referred to as the "orbital element set," establish the size, shape, and orientation of an orbit in space as well as the location of a satellite in its orbit. These parameters, some of which are depicted in Figure 4-6, are as follows:

- Semi-major axis
- Eccentricity
- Inclination
- Right ascension of the ascending node
- Argument of perigee
- Time

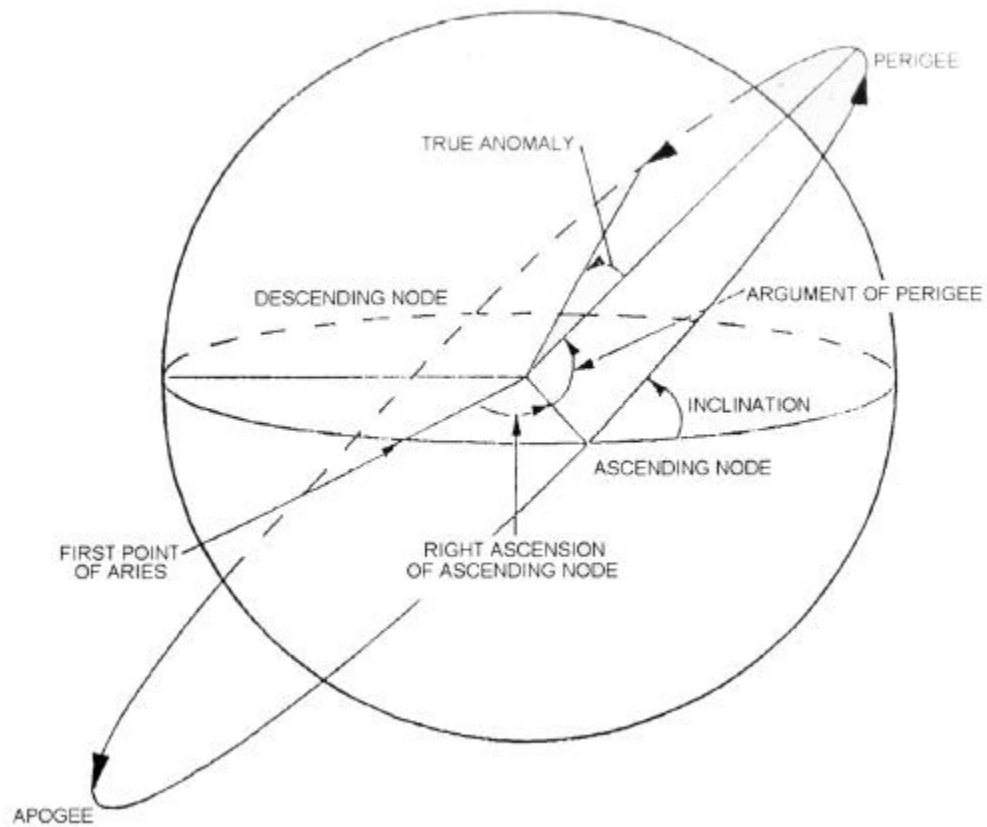


Figure 4-6. Orbital elements.

The semi-major axis is simply one-half the diameter of an ellipse. The length of the semi-major axis is used to define the size of an orbit. From this, the orbital period (the time it takes a satellite to complete one orbital revolution) can be calculated.

Eccentricity defines the shape of an ellipse. For all ellipses, the value of eccentricity lies between zero and one. The larger the value, the more elliptical the orbit. Circular orbits have an eccentricity equal to zero. A satellite orbit with an eccentricity equal to or greater than one will escape the Earth's gravitational field (parabolic or hyperbolic orbit).

The semi-major axis and the eccentricity of the orbit are determined before launch to design the orbit for that particular satellite's mission.

Inclination is used to orient the orbital plane with respect to the Earth. It is the angular measurement made at the ascending node (the point at which a satellite crosses the equatorial plane going from south to north) from the equatorial plane to the orbital plane (see Figure 4-6). Inclination orients the orbital plane to the equatorial plane, and determines the northernmost and

southernmost latitudes covered by the satellite's ground track. Inclination also defines another manner in which orbits are described:

- Prograde: inclination  $> 0^\circ$  but  $< 90^\circ$
- Retrograde: inclination  $> 90^\circ$  but  $< 180^\circ$
- Polar: inclination equal to  $90^\circ$
- Equatorial: inclination equal to  $0^\circ$  or  $180^\circ$

The final element used to define the size and shape of the orbit and the orbital plane is Right Ascension of the Ascending Node. This is the angular measurement in the equatorial plane from the Vernal Equinox (that point determined by a line extending from the center of the Sun through the center of the Earth to the celestial equator at the start of spring) eastward to the ascending node.

The remaining two orbital elements are used to position the orbital plane. The Argument of Perigee orients the orbit within the orbital plane. It is the angular measurement from the ascending node along the orbital path to the point of perigee. Once the perigee point has been determined, the point of apogee is  $180^\circ$  away.

Finally, to determine where a satellite is in its orbit at a specific time, Epoch Time or True Anomaly is used. Epoch Time is an arbitrary time used as a starting point. Normally, the time when a satellite is at the ascending node is used as epoch time. True Anomaly is the angular measurement from the point of perigee along the orbital path to the location of the satellite at the epoch time.

Although period is not categorized as an orbital element, it is very useful in satellite operations. Typically, the period of a satellite is the time it takes to travel from one ascending node point to the following ascending node point (referred to as the "nodal period"). The minimum period a satellite can have and still be in a stable, non-decaying orbit is approximately 87.5 minutes. If there is any less time, the object will eventually reenter the Earth's atmosphere.

## REFERENCE SYSTEMS

Since observational data for a satellite may be derived by any one of a wide variety of types and locations of sensors, an understanding of the common reference systems used is essential. Each reference system is designed for a particular use, fulfilling at least one of the following purposes:

- to locate a specific object in space

- to discriminate between two or more objects in space
- to describe motion of an object in space.

Reference systems may be classified into two basic types, either inertial or non-inertial. An inertial reference system is one in which direction does not change with time. It is used in locating the position of a satellite to establish the orbital plane and the satellite's orbit within that plane. A non-inertial reference system does change direction with time.

The four reference systems typically used in space operations are summarized in Table 4-1 below:

<b>Table 4-1. Summary of Common Reference Systems</b>		
<b>COORDINATE SYSTEM</b>	<b>ORIGIN</b>	<b>USED TO LOCATE</b>
Geographic (Non-Inertial)	Earth Center Earth Radius	Tracking Station
Topocentric (Non-Inertial)	Tracking Station Slant Range	Locate satellite Ref: Tracking Station
Geocentric (Inertial)	Earth Center Geocentric Radius	Locate satellite in space
Orbit (Inertial)	Earth Center Celestial Radius	Locate satellite in its orbit

## **LAUNCH AND ORBITAL MANEUVERING**

Many factors enter into the mission planning and subsequent design of a satellite. One of the most restrictive facets of this planning is the launch environment (i.e., booster, launch site, launch "window").

### **LAUNCH AZIMUTH AND INCLINATION**

Launch azimuth is the direction from the launch site in which a booster is launched. The relationship between the location of the launch site and the launch azimuth to the resulting inclination of a satellite's initial orbit is very specific. The minimum orbital inclination of a satellite is equal to the latitude of the launch site, and is achieved with a launch azimuth of due East. For launches with any azimuth other than due East, the orbital inclination will always be greater than the latitude of the launch site. Practically speaking, a satellite launched on an azimuth between  $0^\circ$  and  $180^\circ$  will have an inclination between  $0^\circ$  and  $90^\circ$ , or a prograde orbit. Satellites launched on azimuths between  $180^\circ$  and  $360^\circ$  will have inclinations between  $90^\circ$  and  $180^\circ$ , or a retrograde orbit.

Most U.S. launches take place from one of two complexes: Kennedy Space Center, Cape Canaveral, Florida, or Vandenberg Air Force Base in California. If a satellite is launched with the Space Shuttle from Kennedy Space Center (which is located at a latitude of  $28.5^{\circ}$  North) on a due East azimuth, its orbital inclination will be  $28.5^{\circ}$  and the limits of its ground track will be between  $28.5^{\circ}$  North and  $28.5^{\circ}$  South latitude. Therefore, the limits of the ground track equal the launch inclination.

### **Launch Site Limitations**

Many safety factors must be considered when launching from a particular site. Of course, one of the safety considerations is not to launch over populated areas. Consequently, there are limitations to the launch azimuths from each site.

Because of safety considerations, the maximum practical inclination from a Kennedy Space Center launch is  $57^{\circ}$ . However, after an initial orbit is established, the inclination of an orbit can be changed by out-of-plane maneuvers (described later in this section), but this is costly in terms of on-orbit propellant. To obtain an orbit with an inclination greater than  $57^{\circ}$ , U.S. satellites are launched from Vandenberg AFB, CA. A significant advantage of launching from Vandenberg is the capability to economically achieve polar orbits, with ground tracks covering all latitudes from the North Pole to the South Pole.

Another limitation induced by the location of a launch site is the affect of the Earth's rotational velocity. The speed of the Earth changes with latitude, ranging from zero mph at the poles to about 1037 mph at the equator. Since the Earth rotates from West to East, all points on its surface have an eastward velocity, with the greatest eastward velocity occurring at the equator. The farther a launch site is from the equator, the less the Earth's rotational velocity imparts energy to the booster. This results in requiring more fuel to get a satellite into orbit, or a tradeoff with the satellite's payload weight to conserve on-orbit fuel. Launching from an equatorial site offers a significant advantage, and is an important consideration since many satellites operate in low-inclination orbits.

### **Launch Window**

Satellite launches take place within a specified time interval referred to as the "launch window." Some of the factors affecting the launch window are:

- Launch and orbit lighting conditions
- Sun angles
- Payload orbit requirements
- Satellite system phasing



- Tracking and communications requirements
- Collision avoidance with other space objects.

During the winter months, the available launch window for lighting conditions alone can be as little as 3 hours per day. When combined with other factors, launch windows become very constrained.

## **ORBITAL MANEUVERING**

It is rare that a satellite is launched directly into its final orbit. A satellite will typically need to change its orbit at least once to be able to perform its mission. For example, the Space Shuttle may deploy a communications satellite designed for placement in a geosynchronous orbit. The Shuttle itself cannot reach geosynchronous altitude, so a small booster attached to the satellite has to be pointed in the proper direction at the right time and place, and thrust for a precise length of time. Then, once it gets to geosynchronous altitude, it will have to thrust again to stay in its desired orbit.

### **Mission Considerations**

After a satellite has been on orbit for a period of time, it is often necessary to change its orbit by thrusting. Firing a spacecraft's thrusters results in a Delta "V"—a change in the satellite's velocity. The amount of fuel used during a burn depends on the desired velocity change and the mass of the satellite. Since the amount of fuel carried is limited, fuel consumption is one of the primary considerations in satellite mission planning, and is critical to mission life.

On orbit, a satellite can thrust in any direction. Thrusting along the flight path, forward or backward, is the most common. Forward thrusting increases a satellite's velocity and is known as a "prograde burn." With prograde burns, the orbital path of the satellite will be raised at all points except the burn point. Thrusting opposite to the direction of the orbit, which slows a satellite down, is called a "retrograde burn." For retrograde burns, the orbit will be lowered at all points except the burn point.

### **Maneuvers**

Most maneuvers may be performed any place in the orbit; however, there are certain points that minimize energy requirements for a particular type of maneuver:

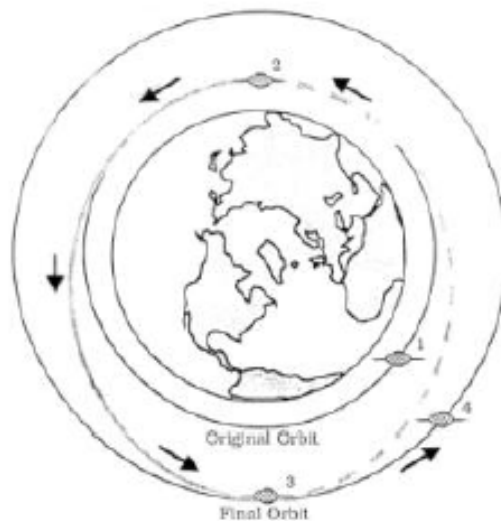
- The most economical method for obtaining a change in orbital period is by applying thrust at perigee or apogee

- The most economical place to perform an inclination change is at either the ascending or descending node
- The most economical place to perform a change in right ascension of the ascending node is at either of the two midway points between the ascending and descending nodes
- The change in inclination or right ascension is easiest if it is performed at apogee
- The most economical place to perform a maneuver to change perigee height is at apogee.

### In-Plane Maneuvers

When a satellite needs to change its altitude, period, or eccentricity, additional energy is required. This energy requirement is true whether or not the element's value is being increased or decreased. The type of transfer used to meet this energy requirement depends on the satellite's mission, and the amount of fuel available.

The most energy efficient in-plane maneuver is known as the Hohmann Transfer (see Figure 4-7). The Hohmann Transfer is a two-impulse maneuver between two co-planar orbits.



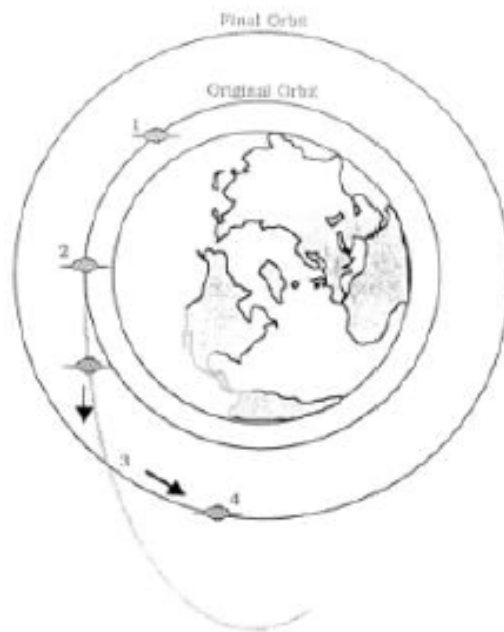
Courtesy of Damon, Thomas D. (2001) *Introduction to Space: The Science of Spaceflight*, Third Edition.  
Krieger Publishing Company.

Figure 4-7. Hohmann transfer.

In accomplishing a Hohmann Transfer, two applications of thrust are required. Each thrust changes the speed of the satellite and places it in a new orbit. If an increase in altitude is

desired, the point of departure becomes the perigee of the transfer orbit and the point of injection into the higher circular orbit becomes the apogee of the transfer orbit. The use of the Hohmann Transfer minimizes the velocity change required, with the advantage of using minimum fuel. The disadvantage of the Hohmann Transfer is that it takes longer than most other transfers. The Hohmann Transfer is used extensively with interplanetary satellites, because it does not require a large maneuver engine or fuel tanks.

Another way to accomplish an altitude change is referred to as the Fast Transfer (see Figure 4-8). This transfer is most useful when time is a critical factor. In the Fast Transfer, the transfer orbit crosses the final orbit at an angle. The burn is performed in two increments but requires substantially more fuel than the Hohmann Transfer. It is, however, the quickest way to get to the final required orbit. The Fast Transfer is typically used by surveillance satellites to reposition over new target areas.



Courtesy of Damon, Thomas D. (2001) *Introduction to Space: The Science of Spaceflight, Third Edition*.  
Krieger Publishing Company.

Figure 4-8. Fast transfer.

## Out-of-Plane Maneuvers

To change inclination or right ascension, an out-of-plane maneuver is required. The inclination maneuver changes only inclination and maintains right ascension. This plane change requires one burn at either the ascending node or descending node of the original orbit. The amount of inclination change depends on the length of the burn.

The right ascension maneuver changes only right ascension without changing inclination. This plane change requires one burn anywhere in the original orbit except at the ascending or

descending nodes. The maximum effect is achieved when the burn is performed midway between the nodes.

## ORBIT TYPES AND APPLICATIONS

The laws of nature force the orbits of all satellites to lie in planes that pass through the center of the Earth. A satellite's ground track is formed by the intersection of the surface of the Earth and a line between the Earth's center and the satellite. As the satellite moves in its orbit, this intersection traces out a path on the ground below it.

### GROUND TRACK

If the Earth did not rotate, a satellite would retrace the same ground on each revolution (see Figure 4-9). Notice that the maximum latitude North and South of the equator over which the satellite passes is equal to the satellite's inclination.

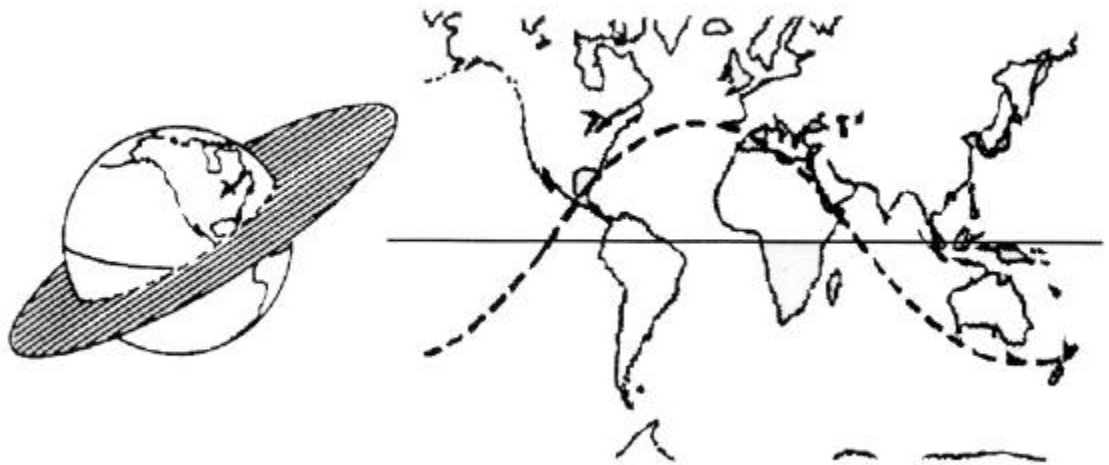


Figure 4-9. Example of ground track (non-rotating Earth).

The orbital plane of a satellite remains fixed in space as the Earth rotates under it. The effect of this rotation is to displace the ground track westward on each successive revolution of the satellite by the number of degrees the Earth turns during one orbital period (see Figure 4-

10). This is referred to as nodal regression. The resulting ground tracks provide operators with an indication of the position of their satellite in accomplishing its mission.

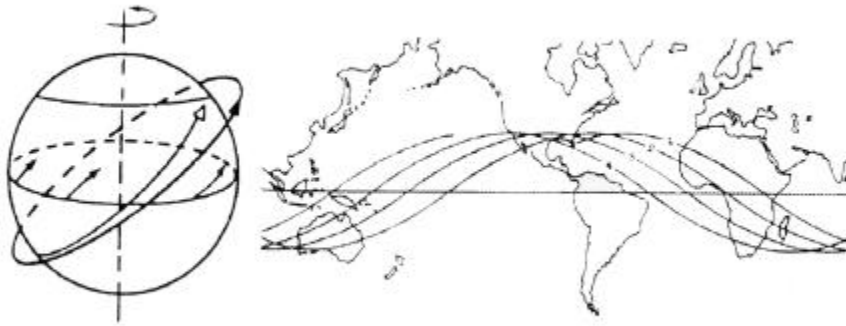


Figure 4-10. -Example of ground track (rotating Earth).

As mentioned above, a satellite in either a circular or an elliptical orbit will trace out a path over the Earth between the limits of latitude as determined by the inclination angle. A satellite in a circular orbit will spend equal amounts of time North and South of the equator. However, a satellite in an elliptical orbit will remain North or South of the equator for unequal periods of time.

Only satellites that are in circular orbits travel along their ground track at a constant velocity. When an orbit is inclined to the equator, the component of satellite velocity in the direction due East or due West varies continuously throughout the orbit. More specifically, a satellite in a nearly circular orbit moves slower in an easterly or westerly direction at the equator and faster when it is at its most northerly or southerly points. The relative speeds of satellites in elliptical orbits vary even more.

## **FIELD OF VIEW**

The field of view of a satellite is defined as the area of the Earth's surface that is in view from the satellite at any given time. Satellites in high orbits have greater fields of view than those in lower orbits.

For example, a satellite at an altitude of 800 nmi has a circular field of view with a diameter of about 4,100 nmi. A satellite at 200 nmi has a circular field of view with a diameter of about 2,000 nmi.

## TYPES OF ORBITS

The various types of orbits are the result of different satellite missions, and the desire for satellites to perform their missions over different areas of the Earth's surface (i.e., have different ground tracks).

### Low Earth Orbit

A satellite is considered to be in a low earth orbit (LEO) at altitudes between approximately 150 and 800 miles above the Earth's surface. At an altitude of approximately 150 miles, a satellite's period will be about 90 minutes. The Space Shuttle and some scientific satellites are typically placed in low inclination, low earth circular orbits.

### Polar Orbit

In contrast to a low inclination orbit and its latitude limitations, a polar orbit passes over the entire surface of the Earth. A polar orbit has an inclination of  $90^\circ$  and is usually circular (see Figure 4-11). Due to the ability to pass over the entire surface of the earth throughout the course of several days, the polar orbit is used extensively by imagery satellites.

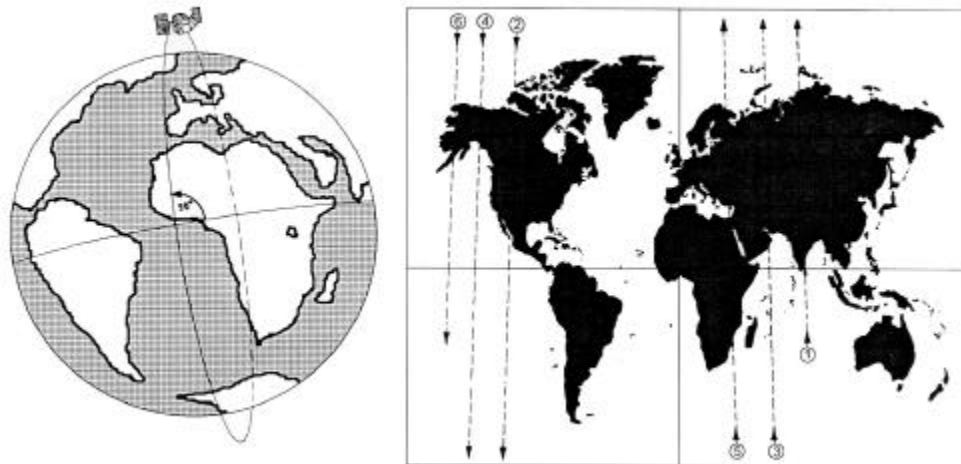


Figure 4-11. Polar orbit.

### Geosynchronous Orbit

A satellite placed in orbit with an average altitude of approximately 19,300 nautical miles (nm) will have an average angular velocity exactly equal to that of the Earth's. Stated more simply, the satellite would have a period approximately equal to one day. This means that it would take as long for the satellite to complete one revolution around the Earth, as it takes for the earth to rotate once about its axis. Such an orbit is called a geosynchronous orbit.

If a geosynchronous orbit with an inclination of  $0^\circ$  were perfectly circular, the satellite would appear to remain stationary in space above the same point on the Earth's surface. This is referred to as a geostationary orbit (see Figure 4-12). This orbit is predominantly used by relay satellites to provide a continuous communications capability among ground stations within their very broad field of view. Some surveillance and warning satellites also use the geostationary orbit. The geostationary field of view is constant, covering nearly one-third of the Earth's surface with latitude limitations of approximately  $70^\circ$  North and South of the equator. Effective satellite communications from a geostationary orbit is not possible at either pole.

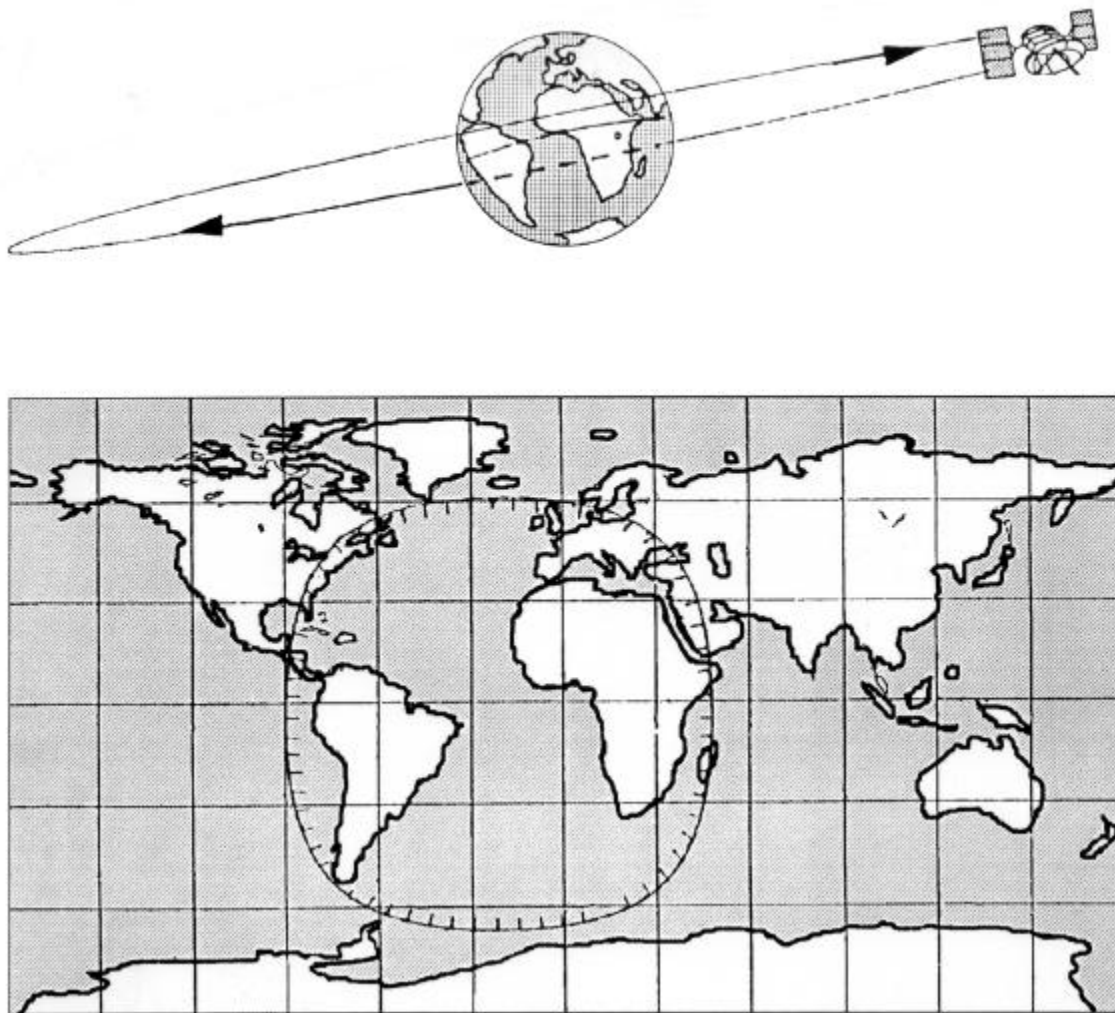


Figure 4-12. Field of View from a Geostationary Orbit.

### **Elliptical Orbit**

To obtain satellite communications capability in the northern or southern latitudes, a highly eccentric elliptical orbit, commonly referred to as a Molniya orbit is used (see Figure 4-



13). The Molniya orbit has an apogee nearly equivalent to the geosynchronous altitude and an inclination of approximately  $63^\circ$  to  $64^\circ$ . A satellite in this type of highly eccentric elliptical orbit slows down at apogee in the Northern Hemisphere (providing longer duration over its greatest field of view) and whips through perigee (smallest field of view) in the Southern Hemisphere. This provides communications in the Northern Hemisphere for nearly 75 percent of the satellite's orbital period. If the apogee/perigee points were shifted  $180^\circ$ , this orbit would cover the Southern Hemisphere.

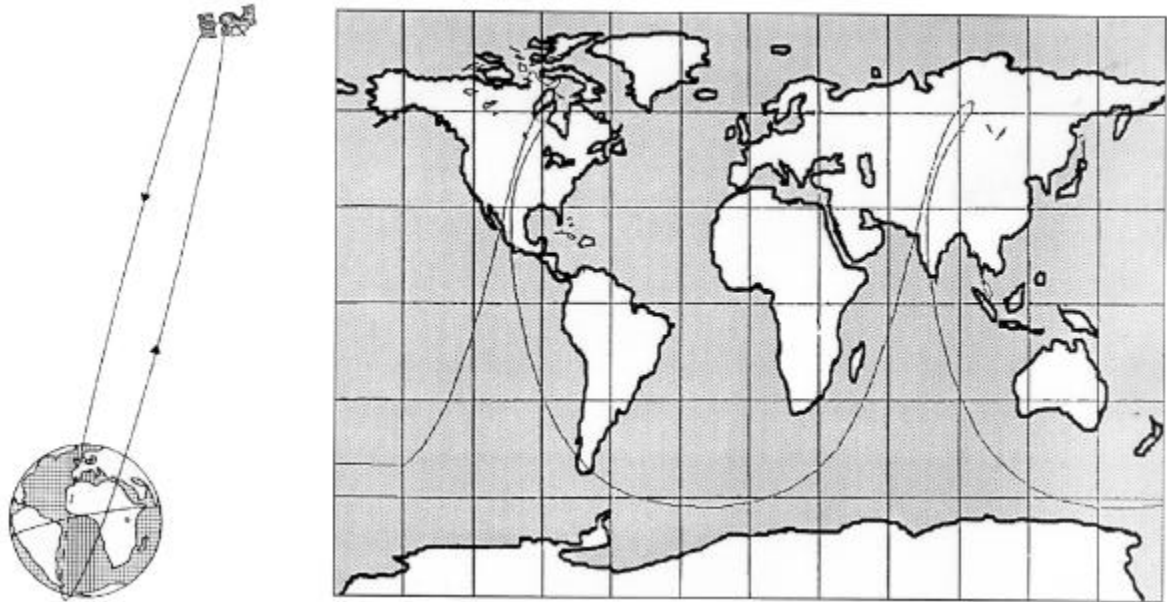


Figure 4-13. Molniya orbit.

### **Semi-Synchronous Orbit**

An average orbit with an altitude of approximately 10,800 nmi results in a period of about 12 hours and is referred to as a semi-synchronous orbit. The purpose of placing satellites in this type of orbit is to allow a user to receive signals from more than one satellite at any time. Navigation and certain kinds of area communications (Molniya) satellites use the semi-synchronous orbit.

### **Sun-synchronous Orbit**

The sun-synchronous orbit takes advantage of the precession of the orbital plane caused by the Earth not being a perfect sphere. All sun-synchronous orbits are highly inclined (normally with inclinations between  $95^\circ$  and  $105^\circ$ ) retrograde orbits that precess eastward around the Earth's polar axis at the rate of one revolution per year. Since the Earth-Sun line also revolves eastward at the rate of one revolution per year, the orbital plane will maintain a

constant orientation relative to the Earth-Sun line (see Figure 4-14). If the satellite's orbital period is then synchronized with the rotation of the Earth, it will pass over the same point on the Earth's surface at the same local time at a regular interval.

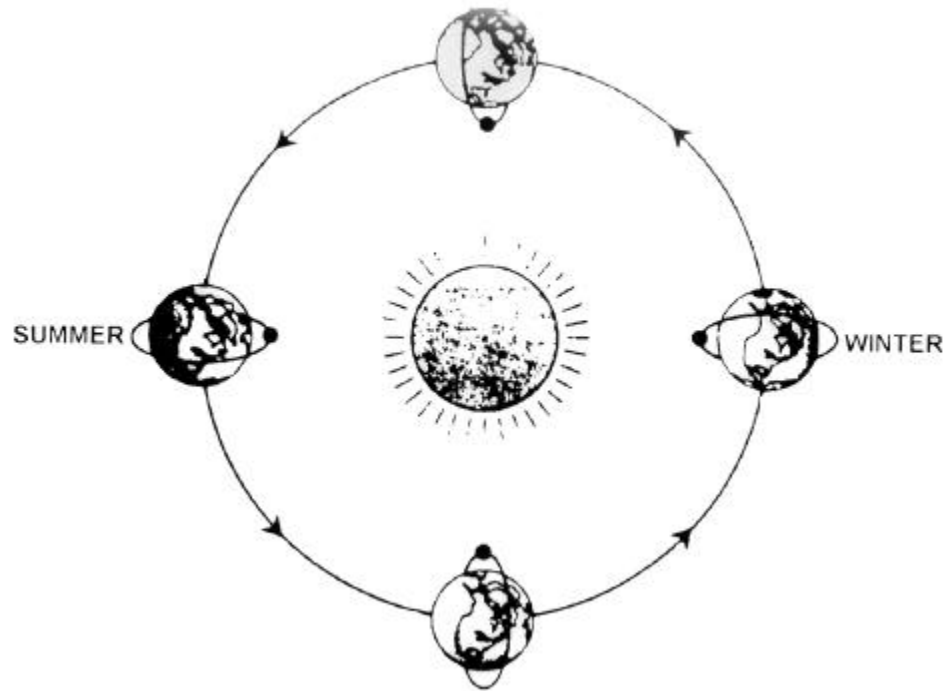


Figure 4-14. Sun-synchronous orbit.

A sun-synchronous satellite ensures that a constant sun angle and uniform lighting exists for the same field of view from revolution to revolution. For certain mission requirements, a noon/midnight sun-synchronous orbit can be selected that would provide good photography for about one-half of every revolution. Most meteorological and earth resources LEO satellites are placed in sun-synchronous orbits, imaging the entire Earth on a regular schedule.

## **ORBITAL PERTURBATIONS AND DECAY**

There are other forces besides the Earth's gravity (referred to as perturbations) which act on an orbiting satellite. Although much smaller, these other forces are of sufficient magnitude to cause orbital decay, and result in significant changes in a satellite's ground track over time if not recognized and corrected for periodically. Changes in a satellite's ground track can result in reduced mission effectiveness. To neutralize the effects of natural perturbations, a satellite may perform "station-keeping" thruster burns.

## **ORBITAL PERTURBATIONS**

The Earth is not a perfect sphere. The North Pole region is more pointed than the flatter South Pole region, and a bulge exists at the equator. This bulge, referred to as the Earth's oblateness, causes the equator to be slightly elliptical.

### **Earth's Asymmetry**

These asymmetrical conditions have an influence on the orbital parameters of satellites in low-and-medium- altitude orbits. One effect of the Earth's asymmetry is positive, in that the nodal regression of an orbit can be timed to make an orbit sun-synchronous without using precious fuel to maneuver for that purpose.

### **Atmospheric Drag**

The Earth's atmosphere does not suddenly end, it gradually tapers off into interplanetary space. Generally speaking, atmospheric drag circularizes and decreases the apogee of a low earth orbit. Any drag caused by air resistance can normally be disregarded above 300 nmi. Occasionally, however, a period of extreme solar activity may occur that will heat the atmosphere and cause it to expand.

### **Third Body Effects**

Newton's Law of Universal Gravitation indicates that there is a force of attraction (gravity) between all objects and bodies in the universe. The gravitational pull of "third bodies" such as the Moon and the Sun can affect the orbits of geosynchronous and deep space satellites.

### **Radiation**

As discussed previously, the Sun is continually expelling matter in the form of ionized gas. The particles in this gas (mostly electrons and protons) that penetrate interplanetary space move with high velocities. These particles, commonly referred to as the solar wind, exert a pressure on satellites, particularly those with large area-to-mass ratios. This pressure induces a restraining force on satellites, and is only present on the daylight (or, windward) side of the Earth. This causes irregular perturbations of a satellite's orbit.

Electrons and protons can become trapped when encountering the Earth's magnetic field. They oscillate back and forth along the lines of magnetic force, and since the magnetic field completely encircles the Earth, the trapped particles completely encircle the Earth. This region of trapped particles, mentioned earlier in Chapter 3, is known as the Van Allen Radiation Belt.

The belt has an inner and outer portion. The inner Van Allen belt starts at an altitude of approximately 250 to 750 miles, depending on the latitude. It extends to about 6,200 miles where it begins to overlap the outer belt. This inner belt extends from 45° North latitude to about 45° South latitude. The outer Van Allen belt begins around 6,200 miles and extends to an altitude that varies from 37,000 to 52,000 miles. The upper boundary is dependent on the activity of the Sun.

## **Electromagnetic Forces**

The Earth's magnetic field extends far into space. As a satellite orbits the Earth, it is traveling through this magnetic field. The electronic components of a satellite also produce a magnetic field that consequently reacts with the Earth's magnetic field. Additionally, the ions and electrons in the Earth's magnetic field collide with the satellite, causing a negative charge on the satellite's surface. The negative charge is larger on the day-side of an orbit than on the night side. The interaction of these induced fields with the Earth's magnetic field causes a magnetic drag to act on a satellite. This drag can cause charging or torquing of a satellite.

## **ORBITAL DECAY AND DEORBIT**

For satellites that pass close to the Earth (low orbit or highly elliptical orbits), we can arrange for the satellite to re-enter, or let it re-enter by itself. Deliberate re-entry of a satellite with the purpose of recovering the vehicle intact is deorbiting. We usually do this to recover something of value: people, experiments, film, or the vehicle itself. The natural process of spacecraft (or any debris: rocket body, payload, or piece) eventually re-entering Earth's atmosphere is decay.

In some situations the satellites are in such stable orbits that natural perturbations won't do the disposal job for us. In these situations, we plan to remove the satellite from the desirable orbit. To return a satellite to Earth (or low Earth orbit), it would take just as much energy as it did to place it in orbit. Obviously it is impractical to return old satellites to Earth from a high orbit. We usually just boost the satellite into a slightly higher orbit to get it out of the way, and there it will sit for thousands of years to come.

## **SUMMARY**

The overall purpose of understanding the principles of orbital mechanics is to recognize the elements that affect the design and planning of a satellite's mission. Many mission planning factors and constraints, such as on-orbit fuel, satellite weight, and launch site considerations, were mentioned in this chapter. However, one factor essential to the planning of a satellite's mission remains to be discussed, and that is the selection of a satellite booster, or launch vehicle.

## **CHAPTER 5**

# **LAUNCH AND RECOVERY SYSTEMS**

### **INTRODUCTION**

This chapter provides an overview of the systems and operations associated with the launch and recovery of spacecraft. The discussion includes a description of the U.S. launch and orbit transfer vehicles used to place payloads into orbit, an overview of launch and recovery operations, a description of the three major U.S. launch sites, a summary of the major ground processing activities that contribute to a successful launch and recovery, and a look at some future launch systems. It should be noted that the information contained in this chapter represents only a snapshot of the current U.S. launch vehicle inventory. As you might expect when dealing with a dynamic industry, this inventory will change as technologies emerge, evolve, and are replaced or removed.

### **BACKGROUND**

During the early years of the space program, both the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) developed launch vehicles to satisfy their own specific requirements. Consequently, there has been a wide variety of launch vehicles used to support the space program. DoD developed the Atlas, Delta, and Titan series of launch vehicles from ballistic missile technology. Meanwhile, NASA developed the Scout and Saturn. Used to send Apollo crews to the Moon, both are now out of production. All these launch vehicles, which can only be used once, are called expendable launch vehicles (ELVs) and each has a different capability to put satellites in orbit. From the least to the most capable in terms of lift, they are Pegasus, Taurus, Delta, Atlas, and Titan. The Pegasus is a recent addition to the inventory of expendable launchers and is aircraft-launched. The Taurus is a ground-launched, mobile vehicle. Currently, there is no one vehicle that can launch all satellites into all the orbits required for the various missions. NASA and DoD select the vehicle best suited for their particular mission based on the size, weight, and desired orbit of the payload. In 1972, President Nixon approved NASA's plan to create a reusable launch vehicle called the Space Shuttle, and directed that it become the primary U.S. launch vehicle, replacing all ELVs except the Scout. This made both NASA and DoD dependent on a single launch vehicle for access to space but, in theory, the resulting high launch rate for the Shuttle would significantly reduce the cost per flight. The Shuttle was first launched in 1981, and was declared operational in 1982. The phase-out of ELVs began. However, in 1984, concerned about having "assured access to space," DoD successfully argued that it needed a "complimentary" ELV as a backup to the Shuttle and initiated what became known as the "Titan IV Program." Production lines for the Delta and Atlas launch vehicles were closed down in anticipation that only the Shuttle and Titan IVs would be used by the end of the 1980s.

After 24 successful missions, the Shuttle program suffered tragedy on 28 January 1986, when the Space Shuttle Challenger exploded after launch. In addition to the human loss, the Challenger accident greatly affected U.S. space policy and demonstrated the vulnerability of relying too heavily on a single launch system. Many military and civilian satellites had been designed specifically to be launched on the Shuttle and could not be transferred to ELVs. The few remaining ELVs had their own problems in 1986. A Titan exploded in April, and a Delta failed in May. These problems also grounded Atlas because of design similarities.

As a result of the 1986 failures, U.S. policy has been significantly revised from primary dependence on the Space Shuttle to a "mixed fleet" approach. Consequently, the country once again has a wide variety of launch vehicles from which to choose. The Shuttle is used primarily for missions that require manned interaction, while ELVs are used to launch spacecraft that are not dependent on crew services. The National Space policy also stated that commercial payloads could be flown on the Shuttle only if they are "Shuttle-unique" (capable of being launched only by the shuttle) or if they involve special foreign policy consideration.

Both DOD and NASA are actively engaged in studying future launch vehicle requirements and designs on a continuing basis. The primary expendable launch vehicles included in the developing mixed fleet inventory are presented in Figure 5-1.

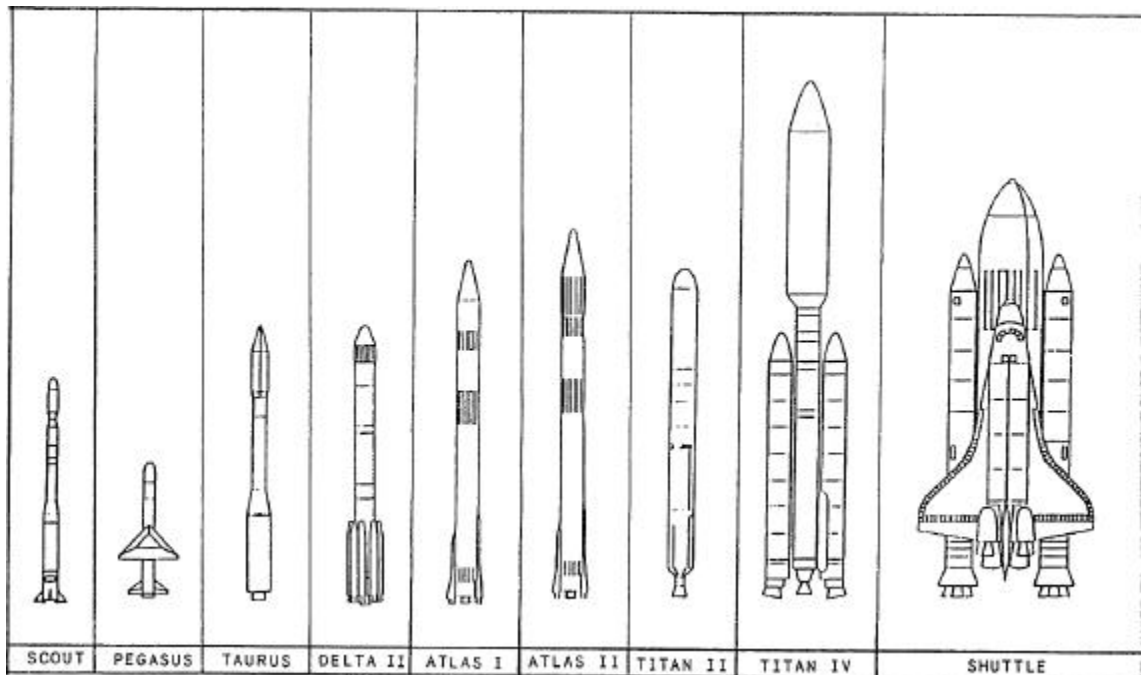


Figure 5-1. Launch vehicles.

To support its aggressive launch requirements, the U.S. maintains three sites for launching expendable and recoverable space vehicles. These launch sites are: Wallops Island, Virginia; Vandenberg Air Force Base (VAFB), California; and Kennedy Space Center (KSC)/Cape Canaveral Air Force Station (CCAFS), Florida.

Wallops Island is the smallest of the three U.S. launch sites and is located on the coast of Virginia at 37° 52' N latitude and 75° 27' W longitude. NASA's Wallops Flight Facility (WFF) is also the farthest U.S. launch site from the equator. The WFF contains payload and booster accommodations and the old Scout launch pad. Launches from WFF are limited in azimuth from 90° to 109°, or from 126° to 129°. Launches within the azimuth from 109° to 126° are prohibited because of safety considerations for populated areas.

Spacelift was assigned to Air Force Space Command (SPACEAF) in October 1990 and is the command's newest operational mission. The term "Spacelift" refers to the capability of the military to project power by transporting people and materiel through space. Spacelift's primary objective is to launch and deploy new and/or replenish existing space forces at any level of conflict. To accomplish its mission, DoD operates the two other launch facilities.

Vandenberg Air Force Base (VAFB) is located on the California coast at 34° 35' N latitude and 120° 38' W longitude. From this location, launch azimuths range from 140° to 208°. This range of azimuths makes Vandenberg the site of choice for polar launches. The Air Force's Western Test Range is also headquartered at VAFB with facilities spanning the Pacific to the Indian Ocean for support of space launches.

NASA's Kennedy Space Center (KSC) and the Air Force's Cape Canaveral Air Force Station (CCAFS) are located on adjoining tracts of land on the east coast of Florida at 28° 28' N latitude and 80° 33' W longitude. Launch azimuths from KSC/CCAFS range from 35° to 120°. This azimuth range, coupled with its lower latitude, allows launch vehicles to use the Earth's rotation to greater advantage. This makes KSC/CCAFS not only the preferred launch site for equatorial and geosynchronous launches, but also the best location for maximizing the lift capabilities of launch vehicles. KSC has three active launch pads. Launch Complexes 39A and 39B are the Space Shuttle launch complexes operated by NASA. Space Launch Complex (SLC's) 41 (Titan IV), while actually on KSC land, is owned and operated by the Air Force. Both KSC and CCAFS have extensive satellite processing and checkout facilities, and frequently make use of each others pads.

CCAFS, located just south of KSC, has six active launch pads. Delta II vehicles are launched from SLCs 17A and 17B; Atlas vehicles are launched from SLCs 36A and 36B; and Titan IV vehicles are launched from SLCs 40 and 41. The launch facilities at CCAFS are controlled by AFSPACCOM's 45th Space Wing, with operational units located on site. While the Air Force's operational facilities are located on CCAFS, the Eastern Range is headquartered a few miles to the south at Patrick Air Force Base.

Table 5-1 identifies the sites used to launch U.S. vehicles, including site location and potential launch azimuth. The far right column lists the launch pads at each of the sites along with their associated launch vehicle in parenthesis.

Table 5-1. Launch Sites					
Launch Base	Country	Location Latitude   Longitude		Launch Azimuth (Approx. Range)	Launch Pads
Kennedy Space Ctr / CCAFS	USA	20° 28′ N	080° 33′ W	35 - 120°	SLC-17A (Delta II) SLC-17B (Delta II) SLC-36A (Atlas II) SLC-36B (Atlas I/Atlas II) SLC-37 (EPAC S-Series Activation) LC-39A (Shuttle) LC-39B (Shuttle) SLC-40 (Titan III/Titan IV) SLC-41 (Titan IV)
Vandenberg AFB	USA	34° 35′ N	120° 38′ W	140 - 208°	SLC-2W (Delta, Inactive) SLC-3E (Atlas, Inactive) SLC-3W (Atlas E) SLC-4E (Titan 34D/Titan IV) SLC-4W (Titan II) SLC-5 (Scout) SLC-6 (Shuttle, Inactive) *SLC-X (Titan IV)
Wallops Island	USA	37° 52′ N	075° 27′ W	90 - 109°/ 126 - 129°	Launch Area No. 3 (Scout) (*Conestoga)
Dryden FRC/ Edwards AFB	USA	N/A		0 - 360°	(Pegasus on NB-52B)
San Marco	Kenya (Italy)	02° 54′ N	040° 20′ E	82 - 130°	San Marco Platform (Scout, Scout II, *Conestoga)
*Proposed					

## EXPENDABLE LAUNCH SYSTEMS

Spacecraft launched via expendable launchers are typically mounted on top of a launch vehicle and upper stage(s) of the rocket. The launch vehicle provides the large amount of energy required to escape the Earth's atmosphere and places the spacecraft into an initial elliptical orbit. The apogee of the ellipse depends upon the required altitude of a given payload and varies from mission to mission. Typically, an upper stage is used to provide the energy necessary to place the payload into its final orbit. If the desired final orbit is circular, the designers can use a single upper stage. Upper-stage ignition will occur when the payload reaches the apogee of the orbital ellipse. The resulting "apogee-kick" places the payload into a circular orbit with a radius equal to the apogee of the ellipse. If the final desired orbit is



elliptical, a second upper stage or a second ignition of a single upper stage is required to place the payload into an elliptical orbit, resulting in a perigee equal to the radius of the initial circular orbit. The apogee is determined by the amount of energy the second upper stage provides.

## **DELTA**

The Delta family of vehicles is built and launched by the Boeing Aerospace Company. Delta II is a medium-lift launch vehicle (MLV) capable of delivering up to 11,800 pounds to low earth orbit (LEO).

The Boeing Delta III is the newest and most powerful version of the Delta family of ELVs. Because of the rapidly expanding commercial space launch market, Boeing was able to develop the Delta III with its own funds. The Delta III, which is essentially a larger version of the Delta II, is capable of placing larger payloads into geosynchronous transfer orbit. The expanded capacity of Delta III will meet the growing intermediate lift requirements for a wide range of domestic and international commercial and government missions.

## **History**

The genesis of the Delta launch vehicle goes back to the days immediately following the launch of Sputnik when the U.S. Air Force intermediate-range ballistic missile, Thor, was modified into a booster for Earth-orbiting satellites. NASA's first attempt to launch a satellite using the Thor-Delta in May 1960 failed, but success followed with the launch of NASA's Echo I satellite on 12 August 1960. From that first success, Delta went on to serve as one of NASA's primary launch vehicles for boosting civil communications, weather, scientific, and planetary exploration satellites into the early 1980s.

After 24 years of service, production of the Deltas came to a halt when the decision was made to launch all spacecraft on NASA's Space Shuttle. Following the Challenger accident, President Reagan announced that the Shuttle would no longer carry commercial payloads, setting the stage for the return of the Delta booster. The U.S. Air Force held a competition for an MLV to place Global Positioning System (GPS) satellites into space, and McDonnell Douglas, now Boeing, was selected for its Delta II configuration. This major contract to produce and launch MLVs for the Air Force beginning in 1989, brought the Delta production lines back into full swing that resulted in larger, more powerful Delta vehicles.

## LAUNCH CONFIGURATION

The Delta II launch configuration is shown in Figure 5-2.

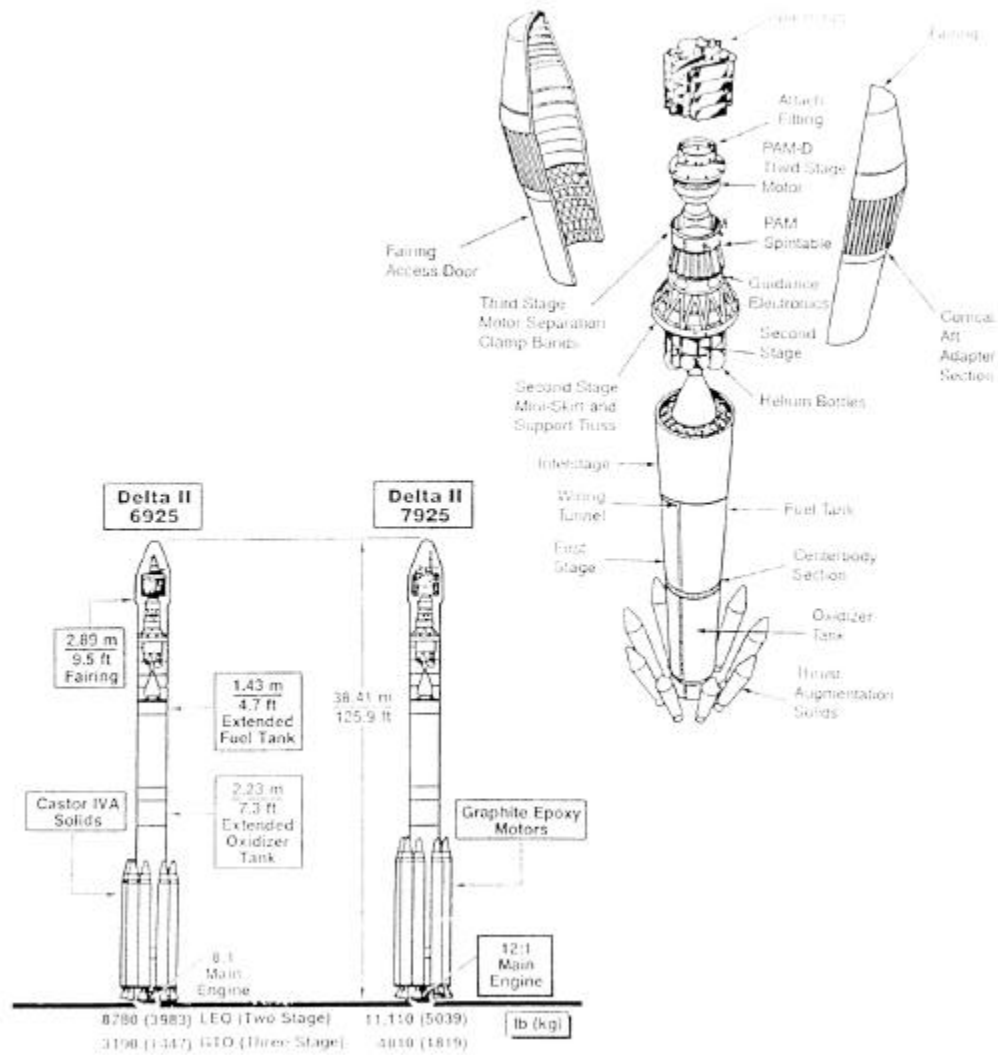


Figure 5-2. Delta II configuration.

## **Mission Application**

The Delta vehicle has launched a variety of payloads including scientific, meteorological, earth resource, and communication satellites. Delta missions have been conducted for NASA, DoD, other U.S. government agencies, foreign government organizations, and domestic private corporations.

In addition to the GPS satellite launches, other recent Delta missions include the Iridium constellation of satellites.

## **Launch Sites**

Delta vehicles are launched from SLC-2W at Vandenberg AFB, and SLC-17A and 17B at Cape Canaveral AFS.

## **Launch Operations**

For each mission, the Delta team undertakes a meticulous, systematic process, typically involving a period of about 3 years. This process includes: advanced mission planning and analysis of spacecraft design; coordination of systems interface between the candidate spacecraft and the Delta vehicle; processing of all necessary documentation, including government requirements; prelaunch systems integration and checkout; launch site operations dedicated exclusively to the user's schedule and needs; and post-mission analysis.

On a typical Delta II geosynchronous mission, the first stage and six of the strap-on solid rocket boosters are ignited on the ground, with the three remaining solid rockets being ignited after burnout and jettison of the first six. Following burnout of the first stage, the second stage is ignited to carry the vehicle into a low-Earth orbit. The vehicle then coasts to a position over the equator, where the second stage is re-ignited. The second, second-stage burn combined with the third-stage burn, inserts the spacecraft into geosynchronous orbit.

Environmental protection for the payload during ascent is provided by an acoustic blanket system inside the fairing. Also, the fairing design allows ample access to the spacecraft when the vehicle is in the launch position with the fairing installed. On command from the second-stage guidance system, the fairing uses a contamination-free joint to separate into two halves. In addition, a 3-meter (10-foot) fairing is used to accommodate even larger spacecraft.

## **ATLAS**

The Atlas II, the latest in a long series of highly successful intermediate-size Atlas boosters, is a 2.5 stage, stainless steel, monocoque design rocket built by Lockheed Martin.

### **History**

In 1951, 7 years before the National Advisory Committee for Aeronautics (NACA) turned over its mission to the newly formed NASA, General Dynamics launched the MX-774, the forerunner of Atlas, later to be developed as an intercontinental ballistic missile (ICBM) for the U.S. Air Force. Based upon early ICBM design, the Atlas booster was first modified to provide a space launch capability in the early 1960s. Since that time, the Atlas has undergone continuous improvements to accommodate larger and heavier payloads with greater mission reliability. Development of the Centaur cryogenic upper stage began in 1958 with the first launch occurring in 1962. Like the Atlas booster, the Centaur was upgraded over the years to accommodate payload growth and to increase reliability.

As the Atlas launch vehicle evolved, it became a primary booster for launching satellites, space probes, and manned spacecraft for NASA. Mated with its high-energy Centaur upper stage, Atlas continues to play a prominent role in space today. The Atlas family of launch vehicles includes four versions with payload capabilities from 5,000 to 8,000 pounds for military and commercial missions.

In 1988, the Air Force selected General Dynamics', now Lockheed Martin, Atlas II for its medium-lift two (MLV-II) launch vehicle program. The Atlas II is an improved and enhanced version of the Atlas G/Centaur expendable launch vehicle (ELV) used in the mid-1980s. Launched in 1991, the Atlas II is capable of placing 6,100 pounds into geosynchronous transfer orbit (GTO) or 14,900 pounds into low-Earth orbit (LEO) (100 nautical miles, 28.5 degrees inclination, circular). The Atlas II has been used to launch the Defense Satellite Communication Systems (DSCS) III payloads for the Air Force.

### **Characteristics**

The Atlas II is liquid fueled, burning RP-1 and liquid oxygen, and uses a one and one-half stage Atlas booster and a Centaur upper stage. The one and one-half stage booster employs Rocketdyne's MA-5A engine system consisting of two booster engines and one sustainer engine, all drawing their propellant from the same tank. The Centaur upper stage consists of two cryogenic restartable engines (Pratt and Whitney RL10s). This upper stage is used to inject the payload into its desired orbit using a combination of suborbital and orbital burns.

## LAUNCH CONFIGURATION.

The Atlas II launch configuration is presented in Figure 5-3.

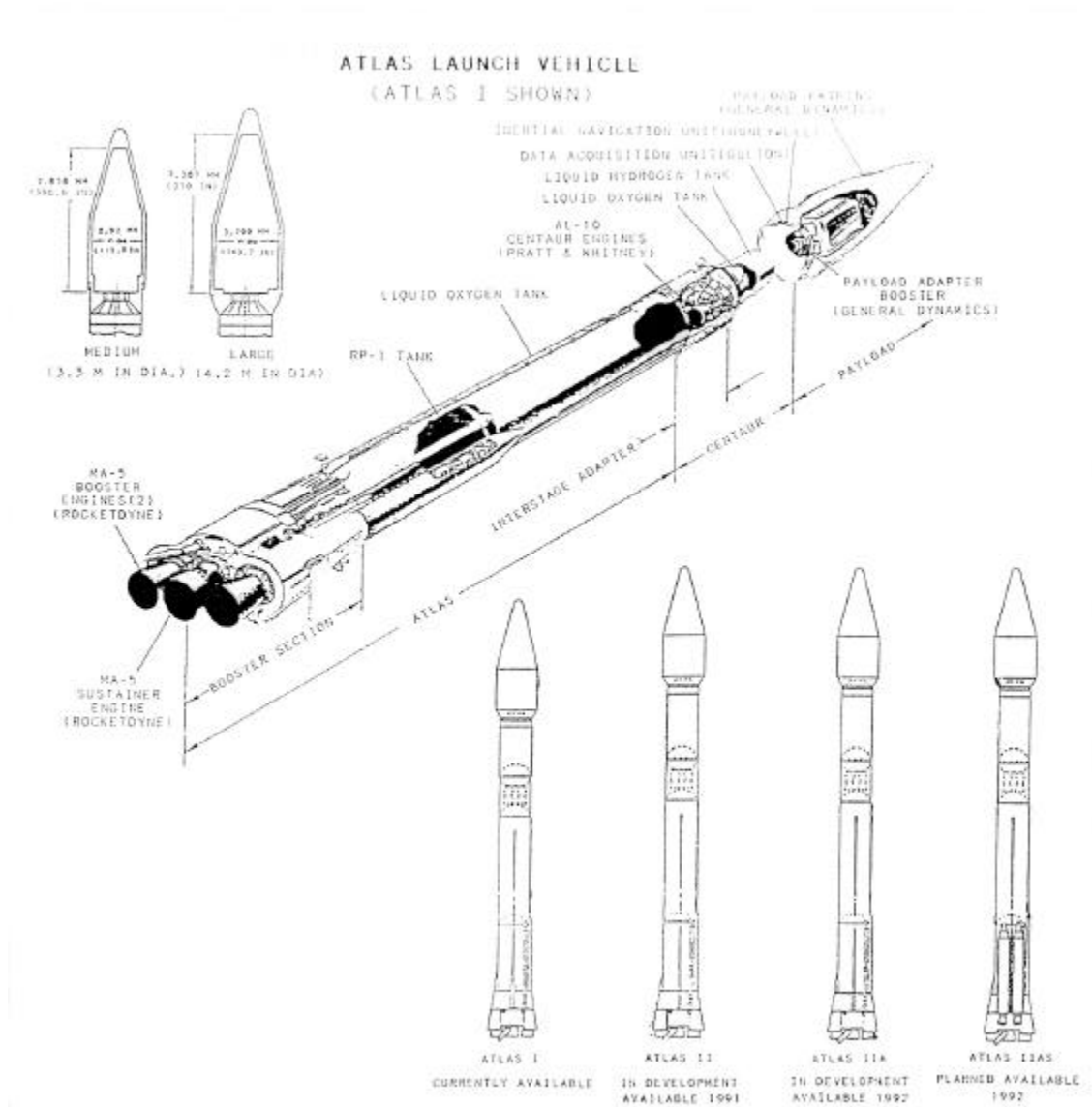


Figure 5-3. Atlas I/II configurations.

## **Mission Application**

In service with both the Air Force and NASA, Atlas vehicles have been used for more than 25 space programs and have launched nearly every unmanned lunar and planetary mission, including Pioneer and Mariner. Atlas missions have achieved many firsts for the U.S. space program. Among them are the first interplanetary flyby and the first American manned orbital flight under the Mercury program.

## **Launch Sites**

Atlas vehicles may be launched from SLC-3E at Vandenberg AFB and SLC-36A or SLC-36B at Cape Canaveral AFS.

## **Launch Operations**

The majority of Atlas processing occurs while the vehicle is on the launch pad. After erecting the Atlas stage, the interstage adapter and Centaur upper stage are installed. After successfully conducting vehicle test and systems verification, the Atlas booster is then ready to mate with the encapsulated payload. The payload fairing checkout, payload processing, and payload encapsulation processes proceed off-line while the booster is readied for flight on the pad. The actual encapsulation and payload/payload adapter mate occur a few days before transfer to the pad. Upon arriving at the pad, the encapsulated payload is mated with the Centaur upper stage and a composite electrical readiness is conducted. The final tanking, ordnance installation, and launch countdown occur in the final days before launch.

## **TITAN**

The Titan IV is the latest in the ongoing evolution of the Titan family of space boosters. First launched in June 1989, the Titan IV now provides the largest U.S. ELV capability to LEO (39,000 pounds to 100 nautical miles, 28.5 degrees inclination, from CCAFS) and to geosynchronous orbit (10,000 pounds with the Centaur upper stage).

## **History**

First launched in 1962, the Titan II was designed as an ICBM that stood alert until 1987. A modified Titan II was also used from 1964 to 1966 to launch the Gemini manned spacecraft into low earth orbit. Lockheed Martin is the prime contractor for the Titan IV program, and is responsible for building the first and second stages, skirts, heat shields, and upper-stage adapters for all Titan IV configurations (see Figure 5-4). The principal Titan IV subsystems include: liquid rocket engines, solid rocket motors, guidance system, Centaur upper stage, payload fairing, instrumentation, and command control receivers.

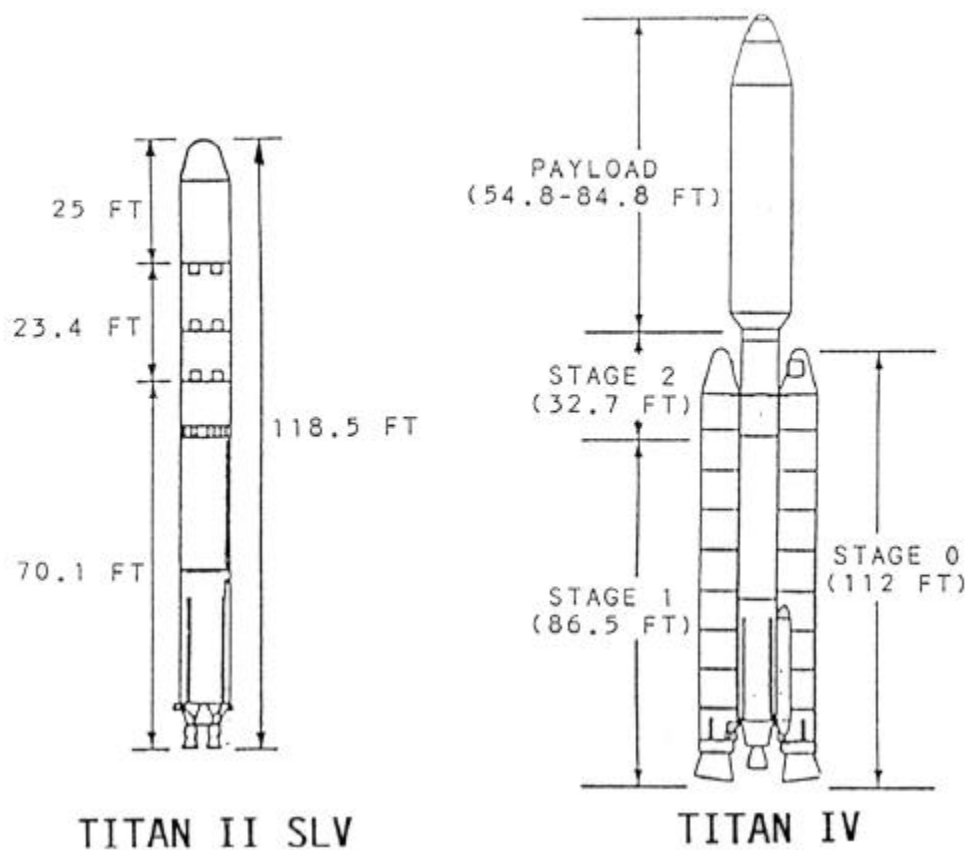


Figure 5-4. Titan II SLV/Titan IV configurations.

### **Mission Application**

The Titan missions are designed to accommodate a variety of civil and military applications including the launch of early warning, reconnaissance, and space science mission payloads.

### **Launch Sites**

Titan vehicles may be launched from SLC-4W (Titan II) and SLC-4E (Titan IV) at Vandenberg AFB, and SLC-40 (Titan IV) and SLC-41 (Titan IV) at Cape Canaveral AFS.

## **Launch Operations**

Lockheed Martin is responsible for manufacturing the core vehicles, activating both launch sites, fabricating the Aerospace Ground Equipment (AGE), and performing system and payload integration tasks. All major subcomponents are shipped to the launch site, where final vehicle assembly, integration, and testing are performed. After production, Titan IV components are transported to either the CCAFS or VAFB for testing, integration, and launch.

## **PEGASUS**

Developed by a privately-funded joint venture of Orbital Sciences Corporation (OSC) and Hercules Aerospace Company, Pegasus is a three- or four-stage, solid-propellant, inertially-guided, winged vehicle that is launched from a L1011 aircraft at 40,000 feet and Mach 0.8. The 50-foot long, 41,000 pound vehicle can deliver a payload of 900 pounds into a low inclination, 250-nautical mile Earth orbit. A new version, the XL, failed on its maiden flight in July, 1994. A modified XL, the XLS, is under development.

## **History**

The first Pegasus mission was funded by the Defense Advanced Research Projects Agency (DARPA) through its Advanced Vehicle Systems Technology Office (AVSTO) with support from NASA Ames Dryden Flight Research Facility (DFRF) and the Air Force Space Division.

The first Pegasus flight was completed successfully from the Air Force Western Range on 5 April 1990. Pegasus was released from the wing of a NASA B-52 carrier aircraft flying on a southerly heading over the Pacific Ocean at an altitude of 43,198 feet. After falling for 5 seconds to clear the carrier aircraft, the three-stage, solid-propellant rocket ignited its first-stage motor and flew an optimal lifting ascent trajectory. It then placed its 423 pound payload into a 273 x 370-nautical mile, 94-degree inclination orbit.

The maiden flight of Pegasus marks the first time that an air-launched rocket placed a payload into orbit. With all mission objectives achieved, the maiden flight validated the fundamental aerodynamic design, established a baseline performance capability, validated the vehicle's Guidance, Navigation and Control (GN&C) system, and validated the aerodynamic and aero-thermal models.



## Characteristics

Pegasus is designed to provide low cost transportation of small satellites (up to 900 pounds) to low-Earth orbit, or larger payloads (up to 2000 pounds) on suborbital ballistic or depressed trajectories. The design uses current, state-of-the-art technology throughout. That achieves reliability at low cost through quality of components and testing rather than full redundancy of systems. The Pegasus system consists of four major elements (other than payload). These elements are the flight vehicle, the carrier aircraft, the airborne support equipment, and the ground support equipment.

### LAUNCH CONFIGURATION.

The Pegasus launch configuration is shown in Figure 5-5.

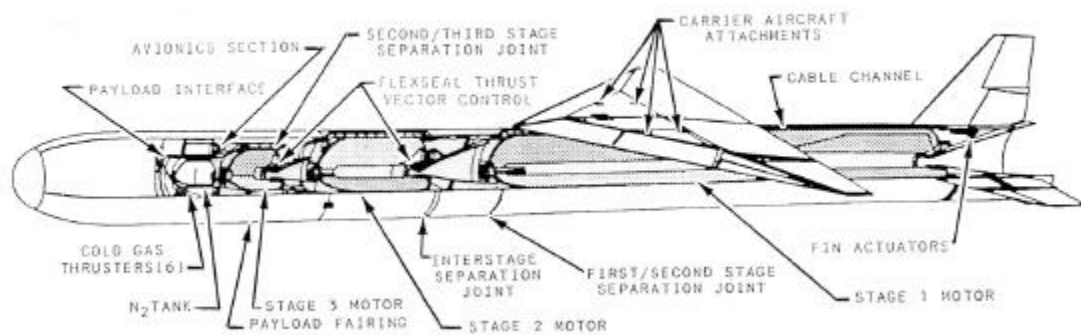


Figure 5-5. Pegasus launch configuration.

### PERFORMANCE PARAMETERS.

Five characteristics differentiate Pegasus from conventional ground-based launch vehicle designs: (1) potential and kinetic energy imparted by the carrier aircraft; (2) propulsion efficiency because of the higher expansion ratio-Stage 1; (3) lower atmospheric density at launch enabling lower weight design and resulting in lower drag losses; (4) lower gravity losses; (5) lower thrust direction losses because of the unique trajectory utilizing wing lift. All these factors combine to yield a vehicle design that delivers nearly twice the useful payload to low-Earth orbit of an equivalent gross weight, ground-based launch system. The basic Pegasus launch vehicle parameters are presented in Table 5-2.

<b>Table 5-2 Pegasus Launch Vehicle Parameters</b>	
<b>Launch Event:</b>	<b>Approximate Time (Seconds After Liftoff):</b>
Liftoff	L + 0
Stage 1 Ignition	L + 108
Solid Rocket Motor (SRM) Jettison	L + 116
Stage 2 Ignition	L + 269
Stage 1 Separation	L + 270
Payload Fairing Jettison	L + 280
Stage 2 Shutdown	L + 494
Park Orbit Insertion	L + 510
Trim Burn	L + 520

## **Mission Application**

Pegasus missions are designed to accommodate a variety of civil and military applications including global personal communications, environmental monitoring, scientific research, and earth observation. Pegasus was conceived to provide a more flexible and more efficient launch system for small space payloads by taking advantage of the many benefits inherent in the airborne launch approach. Independence from shore-based facilities and the capability to base the launch system at numerous airfields worldwide provide greater operational flexibility.

## **Launch Sites**

Launch of the Pegasus vehicle can occur from virtually any over-water launch point with a clear downrange for reentry of the expended first and second stages. This "launch site" flexibility, which eliminates the launch window restrictions of shore-based ground-launch facilities, results in an orbit insertion capability that can achieve any desired combination of orbit inclination and ascending node.

## **Launch Operations**

A primary goal of Pegasus prelaunch processing is to minimize field integration, facilities, and ground equipment. In keeping with this goal, Pegasus is integrated horizontally at a convenient working height. This allows easy access to all areas of the vehicle for component installation, test, and inspection. Custom designed articulated dollies support all integration activities and eliminate the need for lifting motors in the field.

## Launch Sequence/Table

Table 5-3 presents a Pegasus launch sequence (See Figure 5-6) used to place spacecraft into low earth orbit from 40,000 feet of altitude. The time, altitude, and velocities for motor ignition, separation, and burnout events are typical for a trajectory that achieves a 250-nautical mile altitude, circular, polar orbit.

Table 5-3. Pegasus Launch Sequence	
Launch Event:	Approximate Time (Seconds After Liftoff):
Launch-Separation from Carrier Aircraft (40,000 ft., Mach 0.8)	L + 0
First Stage Ignition (39,700 ft.)	L + 5
First Stage Burnout (199,000 ft., Mach 8.1)	L + 81.8
Second Stage Ignition (213,000 ft.)	L + 85.3
Payload Fairing Separation (369,000 Ft.)	L + 124
Second Stage Burnout (556,000 ft., 17,500 fps)	L + 160
Second Stage/Third Stage Coast, Third Stage Ignition (348 nmi, 15,800 fps)	L + 466
Third Stage Burnout & Orbital Insertion (350 nm, 25,043 fps)	L + 531.5

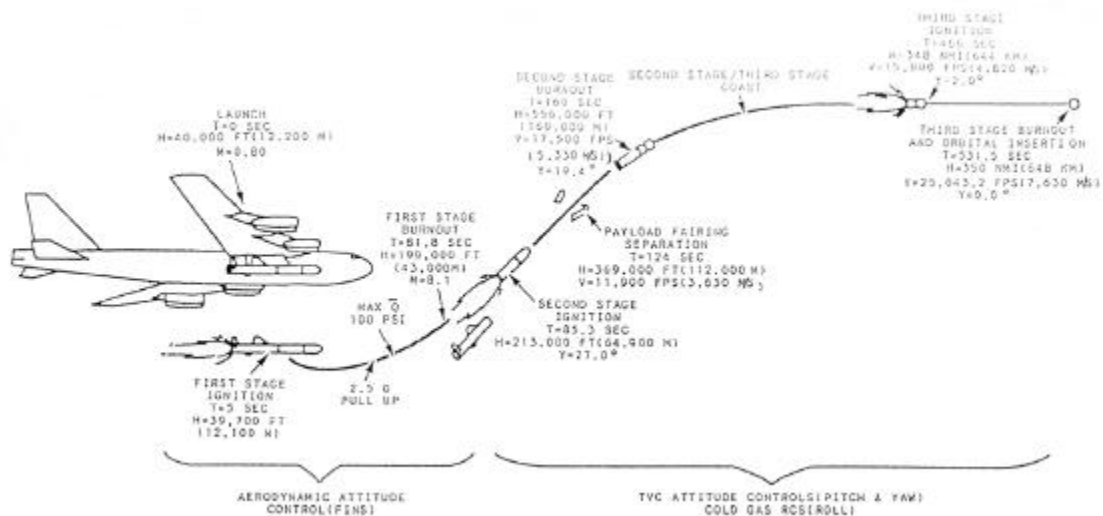


Figure 5-6. Pegasus Baseline Mission Profile.

## **TAURUS**

Taurus is a four-stage, solid-propellant, inertially-guided, ground-mobile, ground-launched vehicle developed by Orbital Sciences Corporation (OSC) as part of DARPA's Standard Small Launch Vehicle (SSLV) program. This 90-foot long, 180,000 pound vehicle is capable of delivering 3,600 pounds of payload to a low inclination, 150 nautical mile Earth orbit.

### **History**

The Taurus concept evolved in early 1989 in response to DARPA's request for an SSLV. Specific SSLV requirements include: full launch system ground transportability; launch from a dry concrete pad; launch system set up time of 5 days or less after arrival at launch site; launch within 72 hours of a command to launch after set up; and launch of a 1,000 pound payload into a 400 nautical mile circular polar orbit from Vandenberg AFB with orbit insertion accuracies of 20 nautical miles in altitude and 0.2 degrees in inclination. The DARPA SSLV contract was awarded in July 1989 and the first launch was in March, 1994.

### **Characteristics**

TAURUS design incorporates state-of-the-art technology throughout the vehicle, and achieves reliability and cost effectiveness through the extensive use of in-production avionics and propulsion systems validated by the Pegasus and Peacekeeper programs. Launch support equipment design is based on hardware developed and proved by OSC under SDIO's Starbird program. The Taurus vehicle's propulsion system is based on motors currently employed on Peacekeeper (MX) and Pegasus. First-stage propulsion is provided by a Peacekeeper Stage 1 solid rocket motor.

### **LAUNCH CONFIGURATION.**

The Taurus launch configuration is shown in Figure 5-7.

### **Mission Application**

Taurus missions are designed to accommodate the same basic complement of missions as Pegasus, with an increased capacity for handling larger payloads.

## Launch Sites

Taurus can be launched from virtually any ground location that provides a dry pad, and a clear downrange for the re-entry of expended stages. As a minimum, a complement of road transportable launch support equipment (LSE) is used to establish a launch site on a dry pad and perform Taurus launch operations. As illustrated in Figure 5-8, major elements of the LSE include motor and motor transfer trailers, an assembly and integration trailer (AIT), a launch equipment van, launch support van, processing and checkout van, hydrolift crane and equipment, cable trailers, generators, launch stool, and portable work platforms.

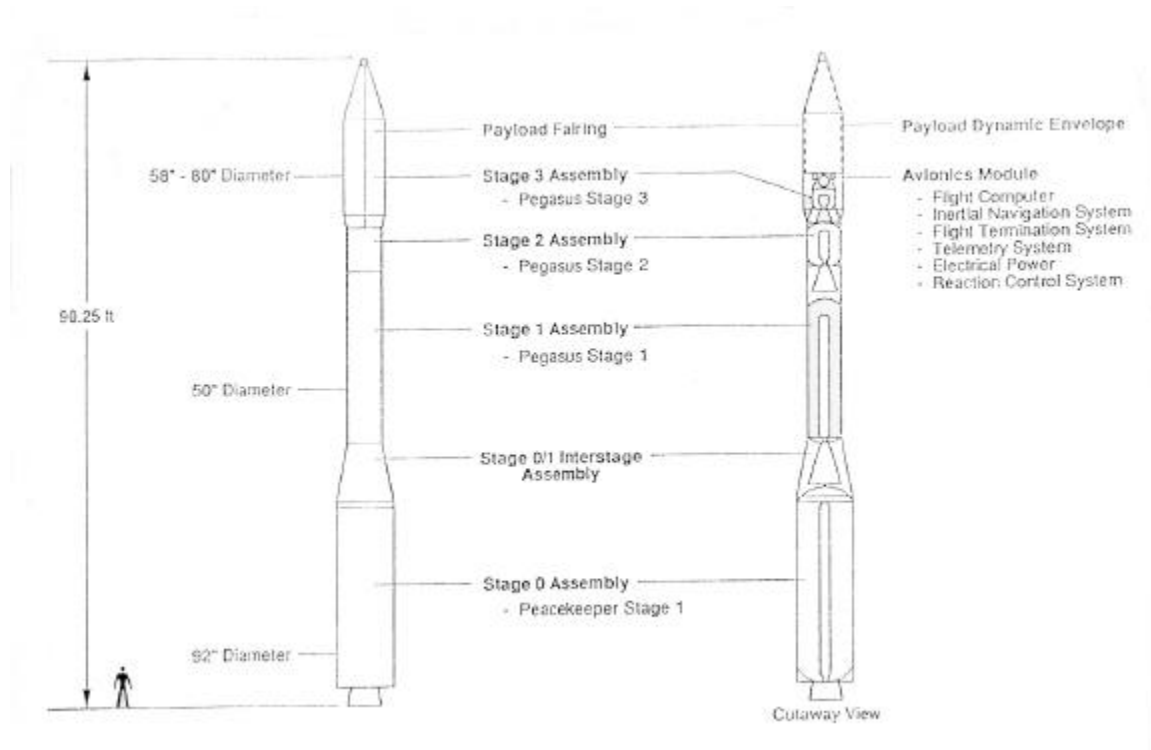


Figure 5-7. Taurus launch configuration.

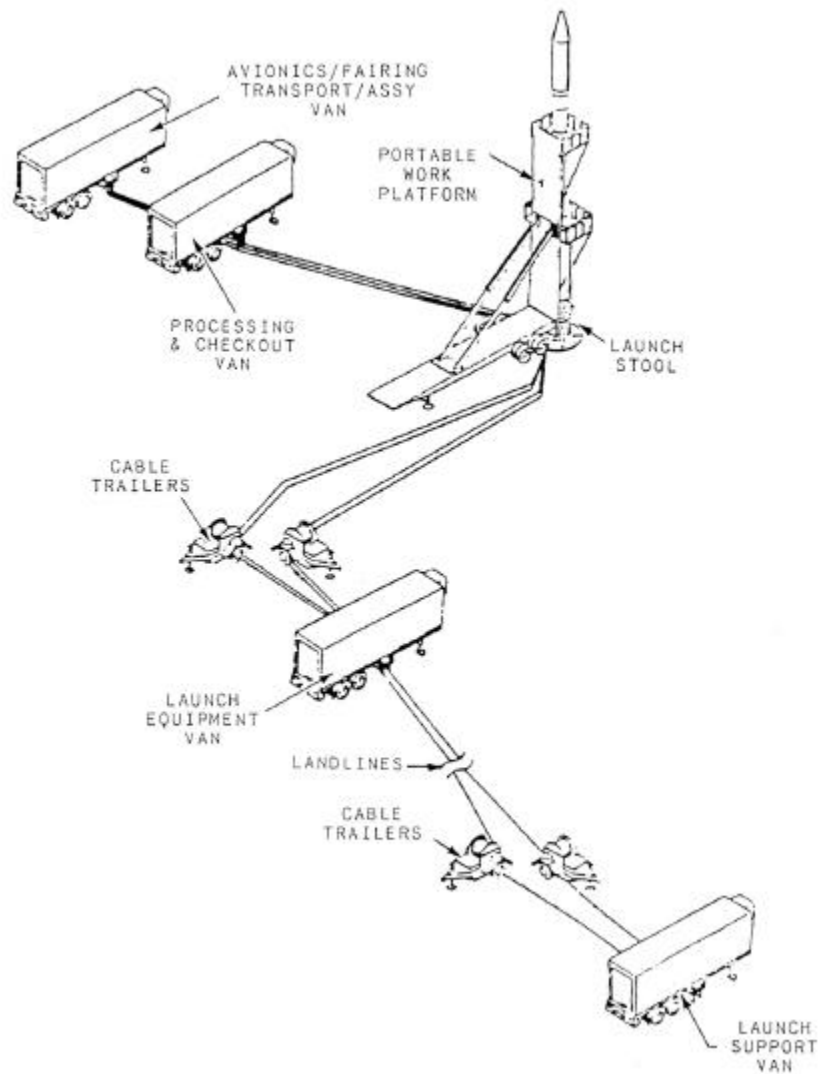


Figure 5-8. Taurus launch pad configuration.

## Launch Operations

Upon arrival at the desired launch site, the LSE is unloaded and positioned. The launch stool is then bolted to the dry pad, cables are connected, and all consoles are checked. Day 3 typically begins with the attachment of the Stage 1/Stage 2 interstage lower section to the top of Stage 1. The combination is then erected onto the launch stool and covered. Finally, the Stage 1/Stage 2 interstage upper section is mounted to Stage 2 and the combination is rolled onto the covered airborne integration trailer.

During day 4 of launch preparation, Stages 2, 3, and 4 are rolled onto the covered AIT where they are aligned and mated. Functional checks are performed on the vehicle's avionics. On day 5, the lifting sling is attached to the Stage 2, 3, 4 stack and integrated systems checks are conducted. Finally, precountdown, range, LSE, and vehicle checks are performed.

When the launch command is received, the 72-hour launch processing flow begins with the integration of the payload to the Stage 2, 3, 4 stack and the performance of integrated tests. Next, umbilicals are connected, the payload fairing is attached, and system level checks are performed. Following completion of successful checks, the hydrolift crane lifts the Stage 2, 3, 4 and payload stack for mating with the already erected Stage 1. Finally, the work platforms are secured and the countdown begins for launch.

## **RECOVERABLE LAUNCH SYSTEMS**

The United States has been sending astronauts into space since 1961. Until 1981, the NASA manned space programs (Mercury, Gemini, Apollo, and Skylab) used each launch vehicle and spacecraft only once. As the U.S. space program evolved, it was decided that a reusable spacecraft and launch vehicle would be more desirable. The long-range goal was to lower cost and make space flight increasingly routine.

## **SPACE SHUTTLE**

The Space Shuttle is a national asset that is capable of deploying a wide variety of scientific and commercial satellites. NASA has used it to service or repair satellites and then redeploy them in addition to bringing spacecraft back to Earth for refurbishment and ultimate re-use. Scientists and engineers have used it as a platform from which to conduct experiments in the micro-gravity of LEO, and study the heavens using onboard astronomical instruments. Capable of performing multiple missions, the Space Shuttle is an effective means for the U.S. to use current and future capabilities in space.

### **History**

On 26 July 1972, NASA selected Rockwell's Space Transportation Systems Division in Downey, California, for the design, development, test, and evaluation of the orbiter. The contract called for fabrication and testing of two orbiters, a full-scale structural test article, and a main propulsion test article. The award followed years of NASA and Air Force studies to define and assess the feasibility of a reusable space transportation system. NASA had previously selected Rockwell's Rocketdyne Division to design and develop the Shuttle's main engines (31 March 1972). Contracts were subsequently awarded to Martin Marietta for the external tank (17 August 1973), and Morton Thiokol's Wasatch Division for the solid rocket boosters (27 June 1974). Rockwell's Space Transportation Systems Division was designated as the integrator for the overall Shuttle system.

As an aside, it is interesting to note that NASA named the first four orbiters after famous exploration sailing ships. In the order they became operational, the orbiters were:

- Columbia (OV-102), named after a sailing frigate launched in 1836, one of the first Navy ships to circumnavigate the globe. Columbia also was the name of the Apollo 11 command module that carried Neil Armstrong, Michael Collins, and Edward (Buzz) Aldrin on the first lunar landing mission on 20 July 1969. Columbia flew its first mission as STS-1 on 12 April 1981.
- Challenger (OV-099), named after a Navy ship, which from 1872 to 1876 made a prolonged exploration of the Atlantic and Pacific oceans. The name was used in the Apollo program for the Apollo 17 lunar module. Challenger flew its first mission as STS-6 on 18 June 1983. Challenger was subsequently lost in a catastrophic launch accident during STS 51-L on January 28, 1986 in which all seven crew members were killed.
- Discovery (OV-103), named after two ships; the vessel in which Henry Hudson in 1610-11 attempted to search for a northwest passage between the Atlantic and Pacific oceans and instead discovered the Hudson Bay; and the ship in which Captain Cook discovered the Hawaiian Islands and explored southern Alaska and western Canada. Discovery flew its first mission as STS-41D on 30 August 1984.
- Atlantis (OV-104), named after a two-masted ketch operated for the Woods Hole Oceanographic Institute from 1930 to 1966, which traveled more than half a million miles in ocean research. Atlantis flew its first mission as STS-51J on 3 October 1985.

On 31 July 1987, NASA awarded Rockwell's Space Transportation Systems Division a contract to build a replacement orbiter using structural spares. The replacement orbiter was completed in 1991, and designated as OV-105, Endeavour.

**Note:** Enterprise (OV-101) the first Space Shuttle "orbiter" was not constructed to be capable of flights in space. It was only used for testing purposes (in-atmosphere gliding flights and practice landings from the Boeing-747 Shuttle Carrier Aircraft (SCA) and ground vibration tests with an external fuel tank and solid rocket boosters). Enterprise now is the property of the Smithsonian Institution and is maintained on display at Dulles Airport outside of Washington, D.C.

## **Characteristics**

The Space Shuttle system is comprised of four primary components including the orbiter, two solid rocket boosters (SRBs), and an external fuel tank. NASA reuses the orbiter and the solid rocket boosters. As the primary component of the Shuttle system, each orbiter is designed to carry crew and payloads into orbit and back more than 100 times. The four major



components of the Shuttle system are depicted in Figure 5-9 and described in the following paragraphs.

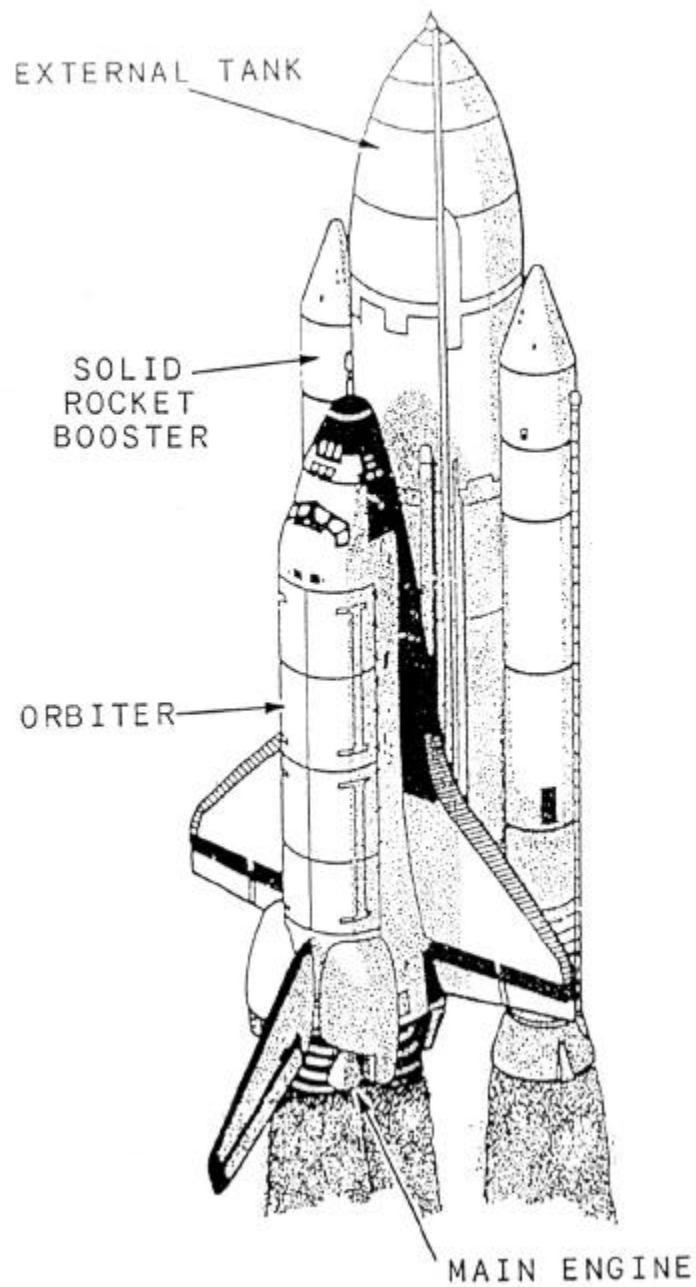


Figure 5-9. Space Shuttle Components.

**Orbiter.**—The orbiter, which approximates the size of a DC-9 aircraft, is 122 feet long. It has a wingspan of 78 feet and a vertical height, measured from the ground to the top of the vertical stabilizer, of 57 feet. As illustrated in Figure 5-10, the orbiter is divided into three main sections: the forward section or crew module where the crewmembers reside; the payload bay; and the aft section containing the three main engines.

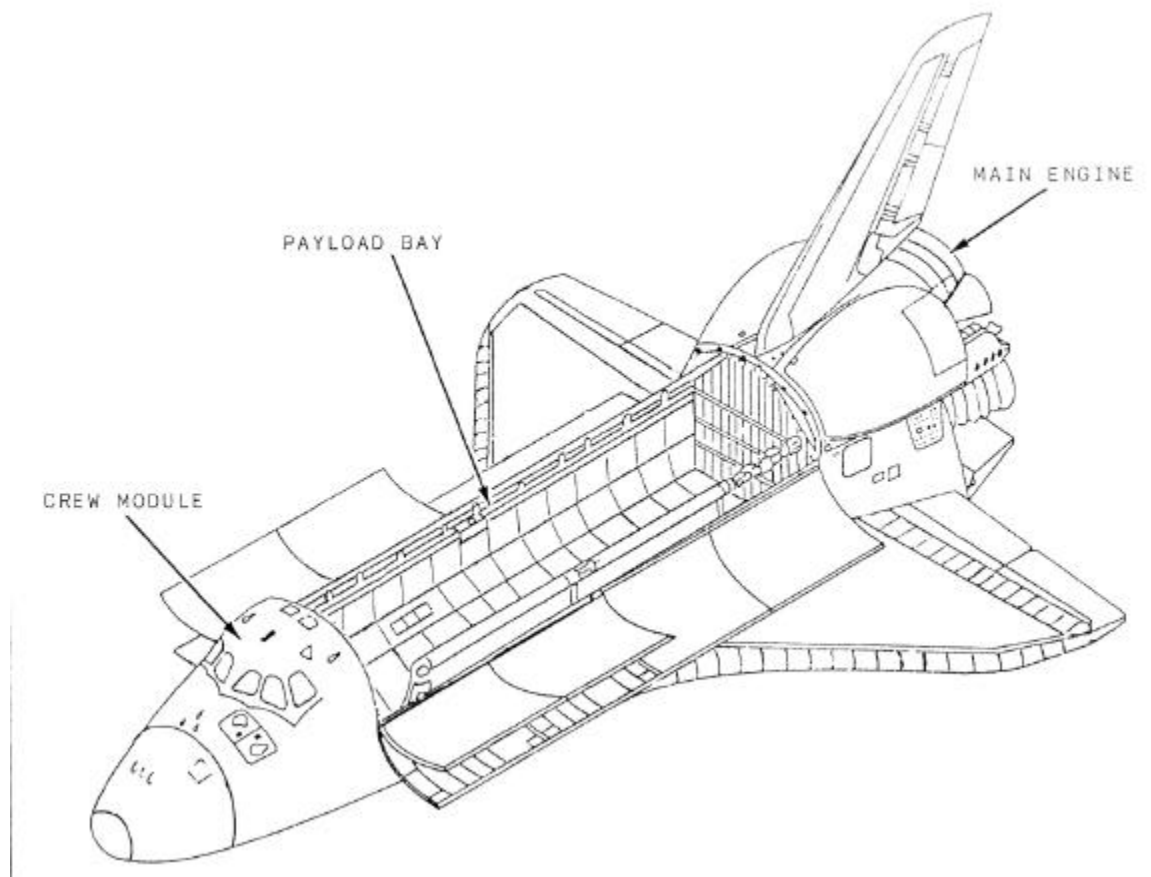


Figure 5-10. Orbiter main sections.

The crew module (see Figure 5-11) is a three-section, pressurized working, living, and storage compartment. It is in this forward part of the orbiter that the cockpit, living quarters, and experiment operator's stations are located.

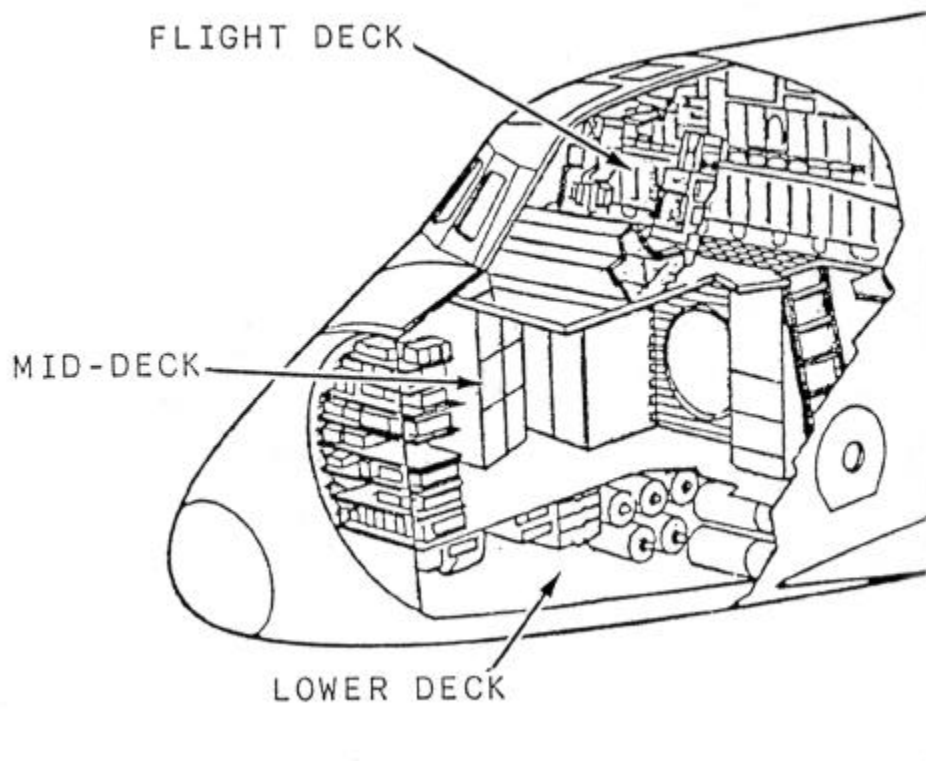


Figure 5-11 Orbiter crew module.

The second major section of the orbiter, the payload bay, is located mid-way between the nose and tail of the orbiter, and measures 60 feet long and 15 feet wide. To put these dimensions in perspective, the payload bay could easily accommodate an average-sized school bus. The orbiter can transport up to 55,000 pounds of payload into orbit, and return to Earth with payloads weighing up to 32,000 pounds.

The third major section, located at the aft end of the orbiter, houses the main engines, body flap, and vertical stabilizer. The three main engines are required to thrust the orbiter into orbit. The body flap is used during re-entry to help protect the main engines from the extreme heat of re-entry. Wings, located in the middle of the orbiter, are used to produce lift when the orbiter is traveling through the Earth's atmosphere on the return from space. The vertical stabilizer consists of a structural fin, which acts as a rudder and speed brake. This rudder can be used to steer the orbiter in a right or left direction during atmospheric flight. During landing the rudder divides in half to act as a speed brake.

**External Tank.**—The orbiter's three main engines receive fuel during the first 8 1/2 minutes of flight from the external tank. The upper area of the tank stores liquid oxygen, and the lower area stores liquid hydrogen. A partitioned area between the two storage areas houses the plumbing that connects the oxygen and hydrogen storage tanks. The outside of the external tank is covered with a material that protects it from excessive launch temperatures. The nose of the tank tapers to a point to reduce aerodynamic drag and the tank's nose-tip also serves as a lightning rod for the Shuttle once it has cleared the launch tower.

The external tank is the only major section of the Shuttle system that is not reused. It is 154 feet long and 29 feet wide. It weighs approximately 78,000 pounds when empty, and 1,667,667 pounds when filled. The fuel oxidizer must be stored in the tank at extremely cold temperatures; liquid oxygen's storage temperature is  $-183^{\circ}$  Celsius ( $-297^{\circ}$  Fahrenheit), while that of liquid hydrogen is  $-253^{\circ}$  Celsius ( $-423^{\circ}$  Fahrenheit).

At launch, the Shuttle consumes about 16,800 gallons of liquid oxygen and almost 45,000 gallons of liquid hydrogen each minute. By burning this fuel and oxidizer, each main engine can produce up to 375,000 pounds of thrust. By the time the main engines shut down, the Shuttle has climbed 70 miles in altitude. The external tank is jettisoned from the orbiter 10 to 15 seconds after main engine cut-off. Once released, the tank begins to tumble and breaks apart as it re-enters the Earth's atmosphere. Pieces of the tank splash down in the Indian Ocean some 58 minutes later.

**Solid Rocket Boosters.**—Because of the large amount of energy required to place the orbiter into orbit, two solid rocket boosters (SRBs) are employed to supplement the main engines and produce the necessary thrust to achieve orbit. One SRB is attached to each side of the external fuel tank, each weighing 1.3 million pounds and standing 149 feet tall and 12 feet wide. The solid fuel is a mixture of aluminum and several other materials that facilitate burning. Each SRB produces 3.3 million pounds of thrust.

The SRBs are fired only after the main engines have started. SRB fuel is consumed during the first 2 minutes of flight by which time the Shuttle has achieved 28 miles in altitude. At that time the SRBs separate from the orbiter with enough residual momentum to carry them upwards for an additional 70 seconds. At their peak of forward travel, the SRBs reach an altitude of 41 miles, before beginning descent into the Atlantic Ocean.

It takes approximately 5 minutes from SRB separation from the external tank until they impact the ocean, despite the fact that they reach a peak descent velocity of 2,900 miles per hour. As depicted in Figure 5-12, three large parachutes slow the rate of SRB descent so that water impact occurs at a velocity of 60 miles per hour. Sea-going tugs recover the SRBs approximately 169 miles from the launch site, and return them to KSC where they are cleaned and refueled for reuse on subsequent flights.



Figure 5-12 Solid rocket booster (SRB) parachutes.

During the extensive investigations that were conducted in response to the Challenger accident, it was determined that a ruptured seal on the right SRB was responsible for the accident. The seals, called O-rings are used to prevent hot gases from escaping from between SRB segments and have since been redesigned. The new design makes the Shuttle a safer space transportation system for future space travelers.

### **Launch Configuration**

In the launch configuration, the orbiter and two SRBs are mated to the external tank in a vertical (nose-up) position on the launch pad. Each SRB aft skirt is attached to the mobile launcher platform by four explosive bolts. The launch configuration is shown in Figure 5-13.

### **Performance Parameters**

For KSC satellite deployment missions, the basic cargo-lift capability for a due east (28.5 degree inclination) launch is 55,000 pounds to a 110 nautical mile orbit using OV-103 (Discovery) or OV-104 (Atlantis) to support a four-day satellite deployment mission. This capability is reduced approximately 100 pounds for each additional nautical mile of altitude. The payload capability for the same satellite deployment mission with a 57-degree inclination is 41,000 pounds. The performance for intermediate inclinations can be estimated by subtracting 500 pounds per degree of plane change between 28.5 and 57 degrees.

If OV-102 (Columbia) is used, the cargo-lift capability is decreased by approximately 8,400 pounds. This difference in upmass capability is attributed to a 7,150 pound difference in orbiter inert weight, 850 pounds of experiments, 300 pounds of additional thermal protection material, and 100 pounds to accommodate thermal cryogenic liquid oxygen hydrogen tank sets for the power reactant storage and distribution system.

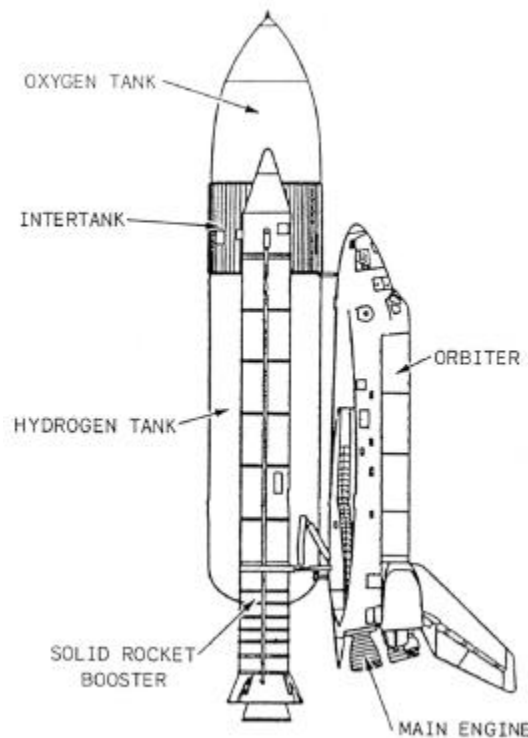


Figure 5-13. Space Shuttle launch configuration.

### **Mission Application**

Shuttle missions are designed to accommodate a variety of civil and military applications, ranging from scientific experimentation, medical and human factors research, satellite repair and deployment, to technology demonstration and certification. The obvious advantage that Shuttle missions have over the ELV missions is the real-time interaction of the crew. The orbiter has carried flight crews of up to eight persons and a 10 person crew could be carried under emergency conditions. During a nominal seven-day mission, the crew compartment is maintained in a "shirtsleeve" environment with the acceleration load not exceeding 3 G's. Representative examples of crew interaction on a variety of missions are discussed in the following paragraphs.

Three hours before the scheduled EVA, the EVA-designated crew members begin breathing pure oxygen to remove nitrogen from their blood streams. Failure to remove nitrogen from the blood would result in an often fatal condition known as the "bends," where the nitrogen gas bubbles collect in the joints of the body. Approximately 30 minutes before EVA commencement, the EVA crew members enter the orbiter airlock located on the mid-deck.

## Launch Sites

Launch of the Shuttle occurs only at Kennedy Space Center's Launch Complex 39. This site contains two identical launch pads which, like many of the Shuttle ground facilities, were originally developed during the 1960s for the Apollo program. Each of the pads, designated Pads A and B, covers an area of approximately one-quarter square mile. To accommodate Shuttle launches, extensive modifications to the pads were necessary. Pad A modifications were completed in mid-1978; while Pad B, finished in 1985, was first used on the ill-fated STS 51-L Challenger mission in January 1986.

Shuttle launches from the KSC site have an allowable flight path of no less than  $35^\circ$  northeast and no greater than  $120^\circ$  southeast. As illustrated in Figure 5-14, a  $35^\circ$  azimuth launch places the spacecraft in an orbital inclination of  $57^\circ$ , whereas a  $120^\circ$  azimuth results in a  $39^\circ$  inclination. Launches further north or south of these two azimuths ( $35^\circ$  and  $120^\circ$ ) would result in over-flying a habitable land mass, adversely affect safety provisions for abort or vehicle separation conditions, or present the undesirable possibility that the SRB or external tank could land on foreign soil.

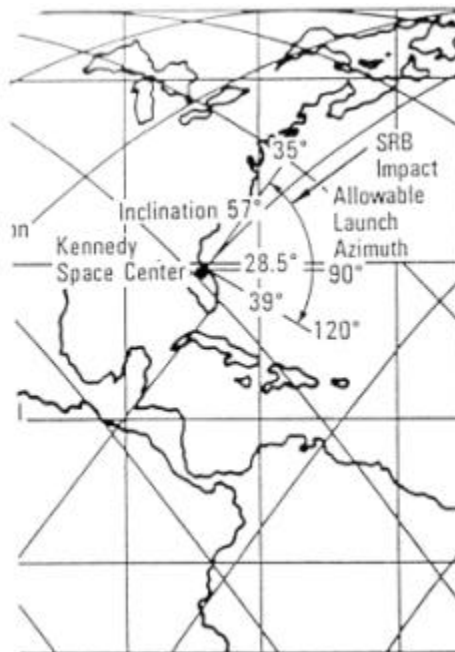


Figure 5-14 Kennedy Space Center Launch Azimuths.

## **Launch Sequence/Profile**

KSC Launch Operations has responsibility for all mating, prelaunch testing, and launch control activities until the Shuttle clears the launch pad tower. Once the Shuttle is clear of the tower, operational responsibility is handed off to the Mission Control Center in Houston, Texas. The Mission Control Center's responsibility includes ascent, on-orbit operations, re-entry, approach, and landing rollout, after which the orbiter is handed over to the post-landing operations team for turnaround.

At launch, the three Shuttle main engines (being fed liquid hydrogen fuel and liquid oxygen oxidizer from the external tank) are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the SRBs. At the proper thrust-to-weight ratio, initiators (small explosives) at eight hold-down bolts on the SRBs are fired to release the Shuttle for liftoff. All of this is accomplished in a matter of seconds.

Maximum dynamic pressure is reached early in the ascent at approximately 60 seconds after lift-off. Approximately 1 minute later (2 minutes into the ascent phase), the two SRBs have consumed their propellant and are jettisoned from the external tank. This is triggered by a separation signal from the orbiter. The SRBs continue to ascend, while small motors fire to carry them away from the Shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate the SRBs for a safe splashdown in the ocean 141 nautical miles from the launch site. The boosters are recovered by tug and returned to KSC.

Meanwhile, the orbiter and external tank continue to ascend, using the thrust of the three main engines. Approximately 8 minutes after launch and just short of orbital velocity, the three main engines are shut down (main engine cutoff), and the external tank is jettisoned on command from the orbiter. The forward and aft Reaction Control System (RCS) engines provide attitude (pitch, roll, and yaw) and the translation of the orbiter away from the external tank at separation. Thereafter, they return it to attitude hold before the Orbital Maneuvering System (OMS) thrusting maneuver. The external tank continues on a ballistic trajectory and enters the atmosphere where it disintegrates. Its projected impact is in the Indian Ocean (except for 57-degree inclinations) for 28.5-degree inclination orbits out of KSC.

Normally, two thrusting maneuvers using the two OMS engines at the aft end of the orbiter are used in a two-step thrusting sequence: to complete insertion into Earth orbit, and to circularize the spacecraft's orbit. The OMS engines are also used on-orbit for any major velocity changes. In the event of a direct-insertion mission, only one OMS thrusting sequence is used. Direct-insertion is a technique used in missions where there are high performance requirements, such as heavy payloads or a high orbital altitude destinations. This technique uses the main engines to achieve the desired apogee altitude, thus conserving orbital maneuvering system propellants. Following jettison of the external tank, only one OMS thrusting maneuver is required to establish the desired orbit altitude, and to circularize the orbit.



Once on-orbit, the forward and aft RCS thrusters (engines) provide attitude control of the orbiter as well as any minor maneuvers along a given axis. The orbiter's velocity on-orbit is approximately 25,405 feet per second, or 17,322 statute miles per hour.

## **Recovery Sites**

One of the "end-of-mission" landing sites is located at KSC. Additional landing sites are located at Edwards Air Force Base, California and White Sands, New Mexico. Contingency landing sites are also provided in the event that the orbiter must abort and return to Earth under emergency conditions.

## **Return Sequence/Profile**

At the conclusion of on-orbit operations, the orbiter is placed in a tail-first orientation using the reaction control system. The two OMS engines are used to slow the orbiter for de-orbit. The reaction control system controls the orbiter until atmospheric density is sufficient for the pitch and roll aerodynamic surfaces to become effective. Entry interface is considered to occur at 400,000 feet altitude approximately 4,400 nautical miles (5,063 statute miles) from the landing site at a velocity of about 25,000 feet per second. At 400,000 feet the orbiter is maneuvered to zero degrees roll and yaw, with an angle of attack equaling 40 degrees.

Entry guidance must dissipate the tremendous amount of energy that the orbiter possesses when it reenters the Earth's atmosphere. This dissipation is necessary to ensure that the orbiter does not burn-up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow), and to ensure that the orbiter is properly positioned to reach the intended point of landing. The thermal protection system covering the entire orbiter provides the protection to survive the extremely high temperatures encountered during reentry.

During the transition phase, the angle of attack continues to decrease, reaching an approximate 14-degree angle-of-attack at 83,000 feet altitude, 42 nautical miles from the landing runway, and traveling at a speed of Mach 2.5. The spacecraft subsequently slows to subsonic velocity as it passes through 49,000 feet altitude at 22 nautical miles from the runway.

The approach and landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 290 knots, 6.9 nautical miles from touchdown. Autoland guidance is initiated at this point to guide the orbiter to the minus -19 to -17 degree glide slope (seven times that of a commercial airliner's approach) aimed at a target 0.86 nautical miles in front of the runway. The Shuttle speed brake is positioned to maintain the proper velocity, with a rate of descent in excess of 10,000 feet per minute (approximately 20 times that of a commercial airliner's standard 3-degree instrument approach angle). At 1,750 feet above ground level, a pre-flare maneuver is initiated to position the orbiter for a 1.5-degree glide slope, and the landing gear is deployed in preparation for landing. The final phase of flight reduces the sink rate of the

spacecraft to less than 9 feet per second with touchdown occurring approximately 2,500 feet past the runway threshold at a speed of 184 to 196 knots (213 to 226 miles per hour). The main landing gear is equipped with a braking system to stop the orbiter on the runway, while the nose wheel is equipped with a steering mechanism to maintain runway heading during rollout, again similar to a conventional aircraft.

## **Recovery Operations**

Spacecraft recovery operations at the end-of-mission landing site are supported by approximately 160 Shuttle launch operations team members. Ground team members wearing self-contained atmospheric protective suits, which provide protection from toxic chemicals, approach the orbiter as soon as it comes to a stop. The ground team members take sensor measurements to ensure the atmosphere in the vicinity of the orbiter is not explosive. In the event of propellant leaks, a wind-machine truck carrying a large fan is moved into the area to dissipate gas concentrations, thus reducing the potential for explosion.

A ground support equipment (GSE) air-conditioning purge unit is attached to the starboard orbiter umbilical to introduce cool air through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and orbital maneuvering system/reaction control system pods to dissipate the residual heat from reentry. A second GSE cooling unit is connected to the port orbiter umbilical Freon coolant loops to provide cooling for the flight crew and avionics during the post-landing system checks. The orbiter fuel cells remain powered up while the crew exits. Designated ground crew personnel are responsible for powering down the orbiter.

At this point, the remaining return processing procedures vary with actual landing site. When orbiter landing occurs at KSC, the orbiter and GSE convoy proceed from the runway to the Orbiter Processing Facility. If it lands at Edwards, the orbiter and GSE convoy proceed from the runway to the orbiter mate and demate facility at Edwards. After a detailed inspection, the orbiter is prepared for ferry atop the Shuttle carrier aircraft from Edwards to KSC. For ferrying, a tail cone is installed over the aft section of the orbiter. This process adds a week to the overall launch processing cycle.

In the event of landing at an alternate site, a crew of about eight members is transported to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the Shuttle carrier aircraft. For landings outside the United States, personnel at the contingency landing sites are provided training on safe handling of the orbiter. Special emphasis is given on crash rescue training, orbiter towing (to a safe area), and prevention of propellant conflagration.

## **ORBIT TRANSFER VEHICLES**

The United States has three primary orbit transfer vehicles (OTVs). Two of the OTVs, the Inertial Upper Stage (IUS), and the Payload Assist Module (PAM), are deployed on-orbit from the orbiter's cargo bay. The third OTV is the Centaur, versions of which have been



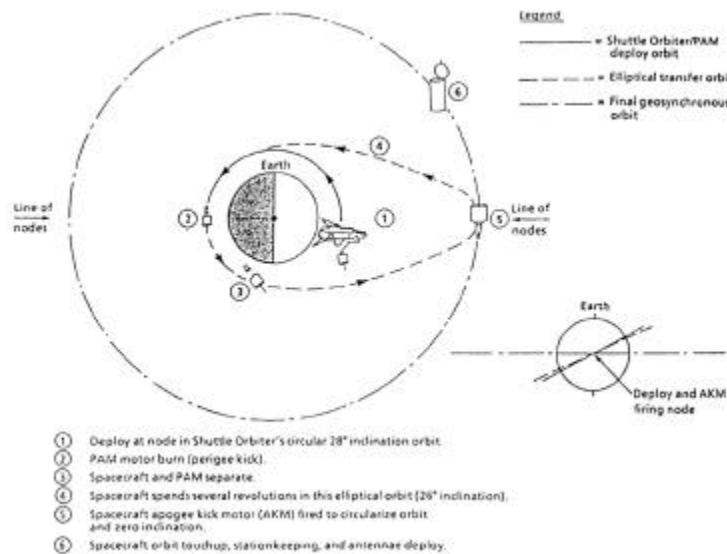


Figure 5-15, view B. OTV flight profile (Space Shuttle).

## INERTIAL UPPER STAGE (IUS)

The IUS is a two-stage vehicle that consists of a forward cone section, Stage 2 solid-rocket motor, an interstage, Stage 1 solid-rocket motor, and a rear staging section. The IUS is built by Boeing Aerospace Company. Figure 5-16 provides a view of the IUS vehicle assembly in its Shuttle cradle.

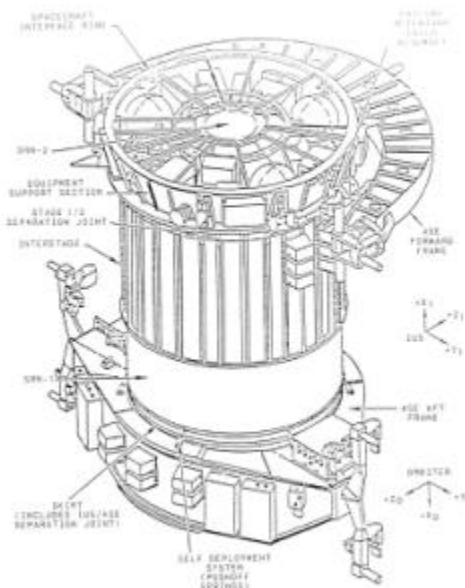


Figure 5-16 IUS vehicle assembly configuration.

The forward cone section provides avionics housing, payload attachment interface, and an equipment bay. The avionics comprises an inertial guidance system and a control system to command and control the payload after deployment from the orbiter. The payload attachment interface provides the mounting surface for attaching the payload. The equipment bay houses the telemetry and tracking systems and the batteries that supply electrical power.

The propulsion system consists of a large solid-rocket motor in the rear and a similar, but smaller, solid-rocket motor in the forward section. Each solid-rocket contains electromechanical actuators to move the nozzle for vehicle control during powered flight while a reaction control system (RCS) provides vehicle control during unpowered portions of flight. The RCS can change the OTV-S/C attitude and spin rates between solid motor burns.

The IUS can place a payload of 5,000 pounds into orbit with an apogee of 19,323 nautical miles, and a perigee of 160 nautical miles, which is the nominal Shuttle orbit from which the IUS is deployed. The IUS has been used on both the Space Shuttle and the Titan launch vehicles.

### **PAYLOAD ASSIST MODULE (PAM)**

Two basic PAMs exist, the PAM-D and the PAM-D2. While the PAM-D2 is slightly larger and has significantly greater payload capacity than the PAM-D, the basic systems and operations are nearly identical. Unless otherwise stated, "PAM" refers to both configurations. The PAM is built by Aerospace Company and Thiokol. Figure 5-17, views A and B, presents a cutaway of the PAM expendable hardware configurations.

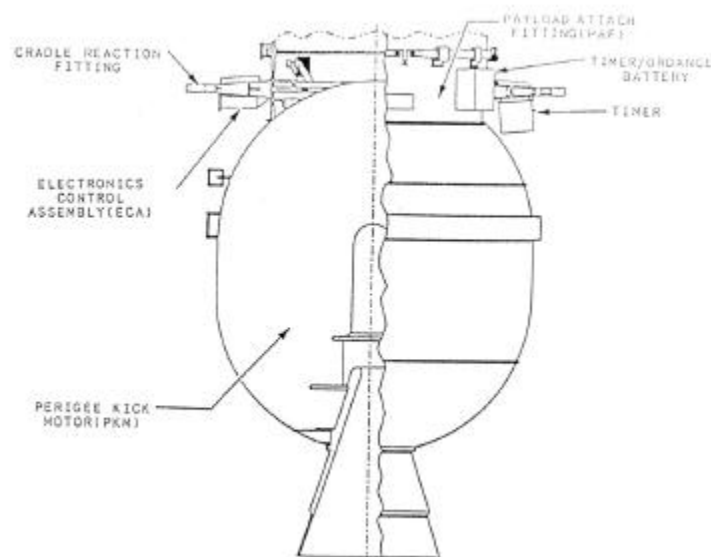


Figure 5-17, view A PAM vehicle assembly configuration.

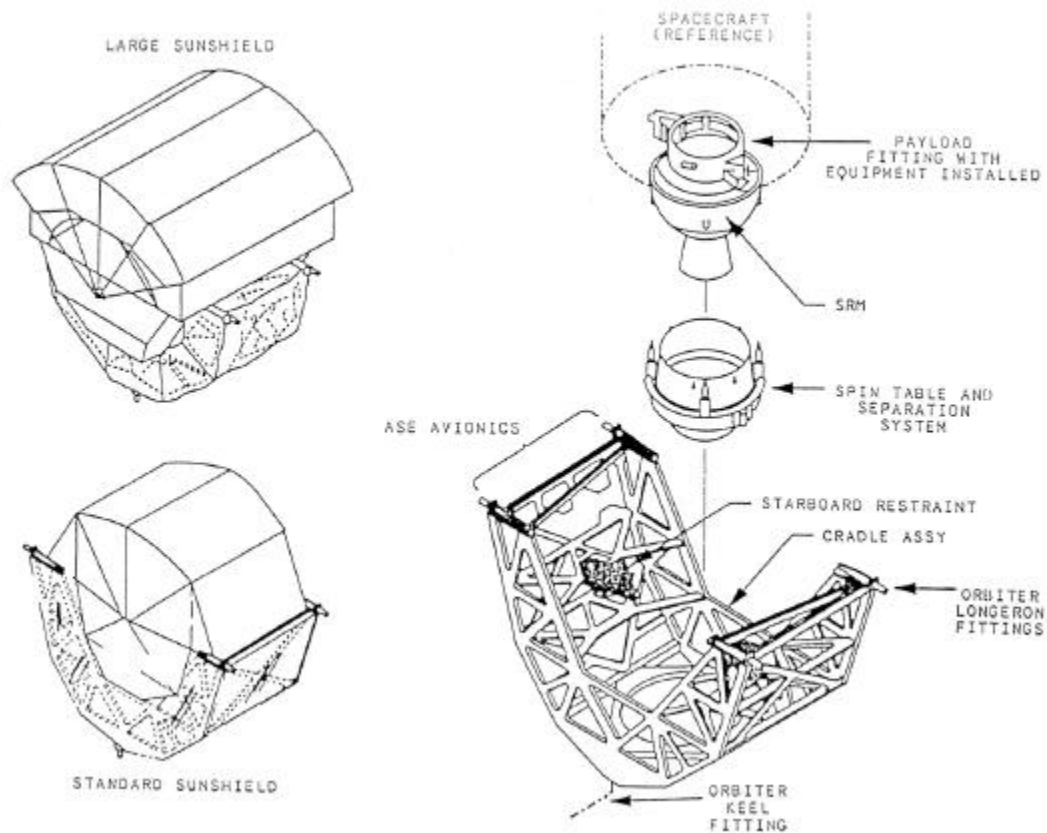


Figure 5-17, view B. PAM with shuttle cradle assembly.

## CENTAUR

Centaur development began in 1958 with its first launch occurring in 1963 on an Atlas booster. In continuous use, and having been regularly modified and upgraded, the Centaur has proved to be a versatile and rugged performer. The Atlas/Centaur vehicle is designed and built by Lockheed Martin. Its engines were developed by Pratt & Whitney Aircraft. Among the Centaur's most notable accomplishments are its successes as the first space vehicle to use liquid hydrogen fuel and the first to perform an in-flight restart using liquid hydrogen engines (1966). During the period of 1966 through 1985, at least one Atlas/Centaur launch occurred each year.

The Centaur vehicle consists of an equipment module, propulsion system, and an adapter. The equipment module provides the payload interface, avionics mounting, and an interface for the adapter in the rear (lower) end. Also housed in the equipment module are the propellant tanks and the engines, the inertial guidance system, and the control system that provides for command and control of the Centaur and the Atlas throughout the mission. The adapter provides the structural connection between the Centaur and the forward end of the

Atlas. Figure 5-19 shows a cutaway of the Centaur, displaying its main systems and interfaces with the launch vehicle and the payload.

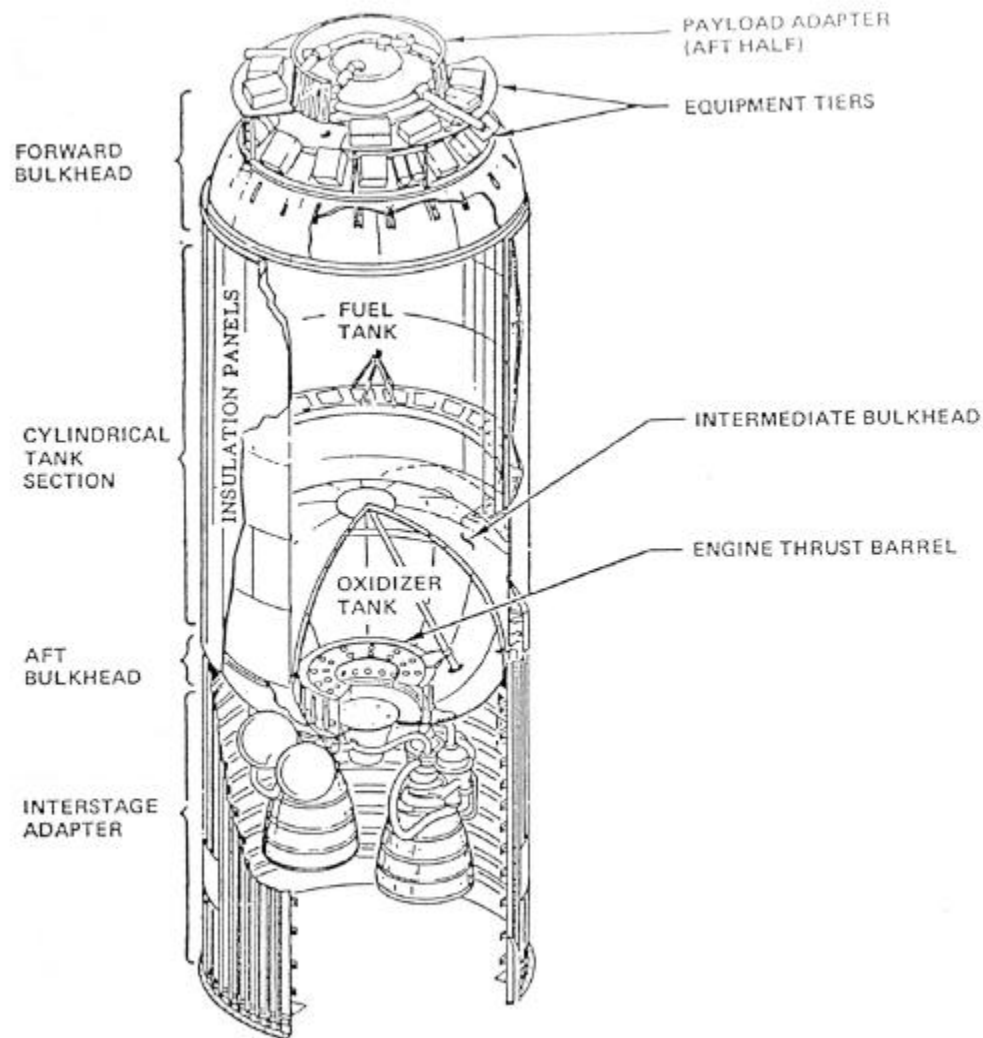


Figure 5-19. Centaur vehicle configuration.

The Centaur measures 30 feet in length and 10 feet in diameter. It uses liquid hydrogen (LH<sub>2</sub>) and liquid oxygen (LO<sub>2</sub>) as propellant. The primary thrust for the Centaur is provided by two turbopump-fed, regeneratively cooled Pratt & Whitney engines developing a combined thrust of 30,000 pounds with a specific impulse of 444 seconds. An advantage in using the Centaur is that the engines can be shutdown and restarted in flight. Hydrogen peroxide reaction-control engines provide attitude control during coast and deliver thrust for propellant settling.

Guidance for the Centaur (and the Atlas booster) is provided by a Honeywell inertial platform system using a reprogrammable digital computer. Primary control functions are provided by a flight control system that directs the two primary engines' thrust. Centaur flight software supports navigation, steering, telemetry tank venting and pressurization, guidance, propellant management, and sequencer functions. The Centaur also implements an S-band transmitter for telemetry, a C-band tracking system, and a DC power system with up to three batteries.

The primary Centaur launch vehicle falls within the Atlas family of expendable launch vehicles. However, the Centaur is qualified for use with Titan IV to provide an additional heavy lift capability for larger payloads.

For over 30 years, the Atlas/Centaur has launched a multitude of planetary and geosynchronous communications spacecraft. For the Navy, the primary payloads have been the FLTSATCOM and the UHF Follow-on satellites.

## **FUTURE LAUNCH VEHICLES**

Although the United States has established an impressive legacy for successfully placing satellites into just about any orbit it desires, a change in how we gain access to space is apparent. The need for better launch systems is already immediate, driven by military, private, and public sector demand. The U.S. military will go into the 21st Century with its 50-year-old rockets, for the Delta, Atlas, and Titan vehicles are built with 1950s ICBM technology. Although these vehicles are extremely capable, they are also very expensive and time consuming to process for launch. The military has often pointed to the need for operationally responsive launch, meaning the ability to put up a satellite when required within a reasonable time from standing start. This, however, is not possible today. According to AFSPACCOM, the quickest time in which a satellite could launch is anywhere from three to six months. Additionally, the cost to put a pound of payload, military or commercial, into orbit with a current U.S. launch vehicle is about double the cost of a foreign launch. Today, a single launch can cost anywhere from \$10 million to \$140 million – and, with the exception of the Shuttle, the vehicle can only be used once.

Affordable and responsive access to space is quickly becoming a pressing issue throughout the satellite launch world. Demand for access to space is accelerating. Some 150 commercial, civil, and military payloads were put into orbit in 1997. One estimate anticipates that up to 1,200 telecommunications satellites alone will be ready for launch between 1998 and 2007. However, the number of planned satellites exceeds the world's total available launch capacity. This unprecedented rush to space has placed pressures on the launch community that can only be resolved by the application of new and innovative launch technologies.



In this country, responsiveness to the changing needs of the warfighter and commercial sector demands for space launch support are two areas that are receiving priority attention. We are on the threshold of seeing a new generation of launch vehicles that will radically transform the economics of space. Both the DoD and NASA have initiated different programs that will improve their respective access to space.

### **The Evolved Expendable Launch Vehicle**

The Evolved Expendable Launch Vehicle (EELV), is a \$2 billion Air Force space lift modernization program. EELV's objective is to reduce launch costs by 25 to 50 percent over the current Delta, Atlas, and Titan systems. In addition to reducing costs, EELV is designed to improve space launch capability and standardization. The program will develop two competing families of launch vehicles, evolved from the current launch systems and components, for government and commercial launch missions in the medium-through heavy-lift classes. Two contractors, the Boeing Space and Communications Group and Lockheed Martin Missile and Space Corporation, were awarded contracts for EELV system development and launch services for 28 missions from 2002 to 2006.

The first launch of the EELV Medium Lift vehicle is scheduled to occur in fiscal year 2001, and the first government payloads on Medium and Heavy Lift Vehicles are scheduled for fiscal years 2002 and 2003 respectively.

Boeing's vehicle, the two stage Delta IV, is a single integrated family of launch vehicles that can be configured for a variety of missions. It will have small, medium, and heavy lift capability and will only spend from 6 to 8 days on the launch pad because of standardized launch pads and streamlined launch operations.

Lockheed Martin's EELV is based on a family of two vehicles, a medium/intermediate launch vehicle and a heavy lift launch vehicle. To reduce costs, these vehicles feature a number of common elements including a Common Core Booster, propulsion system, upper stages, payload adapters, avionics, as well as simplified launch pads and streamlined launch operations. The medium/intermediate class configuration will use a single Common Core Booster. For heavy class payloads, three Common Core Boosters will be strapped together. To achieve final orbit insertion, the EELV will use the Centaur upper stage. The Centaur is capable of placing a payload into geosynchronous transfer orbit or directly into geosynchronous orbit. The first operational launch of Lockheed Martin's EELV is planned for the year 2001 from Cape Canaveral Air Station, FL.

### **Space Plane**

Another initiative sponsored by the Air Force is the development of a reusable vehicle intended to launch a variety of small military satellites in the next century by operating like an airplane or "space plane".

The space plane system, known as the Space Maneuver Vehicle (SMV) or X-40A, is being developed by the Boeing Company. It will integrate several components into one launch vehicle. The space plane will be the launch vehicle and will serve as the first stage to deliver payloads to orbit. A Modular Insertion Stage (MIS) is designed to deliver satellites in the 2,000 to 3,000 pound range into orbit upon separation from the space plane. The MIS will be an expendable element of the system, while the SMV will be flown back to Earth to be used again.

The SMV is intended to launch only military spacecraft that would not be eligible to be launched on commercial systems. It is perceived as a "force multiplier" that will provide additional capability by delivering small tactical satellites deployed in a rapid reaction manner. The space plane is envisioned as a launch-on-demand system having a short period between payload delivery and launch. The objective is to launch the same day as delivery as long as the payload is ready to go and be ready to launch again in 72 hours. The program goal is to have the system operational by 2010.

### **Single-Stage-To-Orbit**

NASA's newest entry into the space launch arena is the single-stage-to-orbit (SSTO), *VentureStar*. NASA's objective is to build a much cheaper version of the space shuttle; one that can be used several times a week rather than a few times a year.

As long as launch systems depend on expendable components, the price of a space launch has a limit below which it cannot go. One way to dramatically reduce launch costs is to develop a fully reusable, SSTO launch vehicle. This type of vehicle would break the "cost barrier", lowering launch costs to a fraction of today's prices. The *VentureStar* is an attempt to accomplish this.

The Lockheed Martin reusable SSTO offers a new approach to space transportation. The vehicle is designed to have an aerodynamically lifting body for efficient launch and cooler re-entry. It will use linear spike engines that will provide maximum performance with minimum weight. To reduce the vehicles overall weight, advanced composite materials will be used for structures and propellant tanks. Ground operations will be patterned after aircraft maintenance procedures, providing rapid turnaround.

Under a cooperative agreement, Lockheed Martin is investing with NASA to fund development of the *VentureStar* prototype X-33 technology demonstrator. The X-33 test flights are scheduled for 1999 and will provide the basis for a decision to transition to *VentureStar* early in the twenty-first century. The goal of the cooperative agreement is to lead to a privately owned and operated space transportation system, which will dramatically reduce the cost of access to space by as much as 10-fold.

However, since the first VentureStar will not be capable of carrying a crew, DoD has approached industry to explore options for carrying to orbit both human and non-human cargo early next century. One option being looked at is a small experimental vehicle known as the X-34. This vehicle will test two-stage-to-orbit technologies, including a new type of reusable ceramic tile. Initial test flights are scheduled to begin in 1999.

The objective of the X-34 is flight demonstration of key reusable launch vehicle operations and technologies directed at the RLV goals of low-cost space access and commercial space launch competitiveness. The vehicle is being designed and developed by Orbital Sciences Corporation.

A nominal flight profile consists of a drop from an L 1011 aircraft, engine start and acceleration to Mach 8 with an altitude of 250,000 feet, with a coast phase, followed by re-entry and landing. Aircraft type airframe and controls are key enabling features of this launch vehicle.

## **Sea Launch**

The concept of Sea Launch is to be able to launch commercial satellites to any inclination from a platform at sea. Once in operation, a launch platform and a command ship will sail from their homeport of Longbeach, CA, to a point 1,400 miles southeast of Hawaii, near the equator. From that location, the launch vehicle and payload will achieve the shortest possible route to orbit of about 26,000 miles. This factor, plus being able to take the greatest advantage of the Earth's rotation of about 1,000 mph at the equator, will potentially offer one of the most cost-effective launch service available.

Sea Launch Company was formed in April 1995 in response to growing market demand for a more affordable, reliable, capable, and convenient commercial satellite launching service. Sea Launch intends to be able to offer customers more flexibility, capability, and convenience than existing systems.

Sea Launch Co. is a limited duration corporation formed in the Cayman Islands, with offices in Oslo, Norway and Seattle, Wash., and a U.S. Home Port facility in Long Beach, Calif. The company is owned by Boeing Commercial Space Co. of Seattle, Wash. (40%); RSC-Energia of Moscow, Russia (25%); Kvaerner Maritime of Oslo, Norway (20%); and KB Yuzhnoye/PO Yuzhmash of Dnepropetrovsk, Ukraine (15%). Financing for the venture is being provided by these companies, and through debt financing arranged by Chase and Chemical Bank, New York, NY, U.S.A., with the participation of the World Bank.

Marine-based operations and highly automated systems, coupled with a customized launch location, will deliver up to 5,000 kilograms of payload to geostationary transfer orbit. The first demonstration launch was successfully accomplished in March 1999.

Two unique ships form the marine infrastructure of the Sea Launch system. The first is an Assembly & Command Ship (ACS), and the second is the Launch Platform. Both vessels are equipped with spacecraft handling and launch support systems.

The ACS is a specially designed vessel that will serve as a floating rocket assembly factory while in port, and will provide crew and customer accommodations and mission control facilities for commanding launches at sea. It is 660 feet long, about 106 feet wide, with a draft displacement more than 30,000 tons and has a cruising range of 18,000 nautical miles. The ACS provides accommodations for up to 240 people and has medical facilities, dinning room, recreation, and entertainment facilities.

The LP is a former North Sea oil drilling platform and was refurbished at the Rosenberg Shipyard in Stavanger, Norway. The vessel is the largest semi-submersable, self-propelled vessel in the world. It is equipped with a large, environmentally controlled hangar for storage of the Sea Launch rocket during transit, and with mobile transporter/erector equipment that is used to roll out and erect the rocket in launch position prior to fueling and launch. Special facilities onboard enable the storage of rocket fuels (kerosene and liquid oxygen) sufficient for each mission.

As a testament to commercial confidence with this innovative concept for launching satellites, Sea Launch already has firm contracts for 18 commercial launches. Significantly however, this approach represents a major shift in our strategy for gaining access to space. U.S. companies are being encouraged by to develop new and more cost-effective ways of getting to space, even if it means forming international consortiums with former adversaries. Many aerospace companies from the former Soviet Union have extensive experience with space launch which now can be capitalized on. Not only is the technology of getting into space changing, but so is the business of doing business in space changing.

## **SUMMARY**

The objective of the DoD space program is to launch satellites for warning, surveillance, communications, weather, and navigation systems to support our military forces on a world-wide basis. To meet the needs of these mobile forces around the world, the military relies heavily on highly capable space systems and is therefore dependent on a reliable, capable, and available launch system. The U.S. space community fully recognizes the problems inherent with our space launch infrastructure. The military, civilian, intelligence, and commercial sectors each have unique requirements that must be satisfied by a national space program. Looking at the complexity of our varied requirements one can easily see that this is no trivial challenge. Fortunately the U.S. space community is stepping up to that challenge. We are redefining the space agenda as new concepts for improving space launch are being evaluated, developed, and deployed. As a nation we are on the threshold of entering a new era in gaining access to space and firmly establishing ourselves as the world's pre-eminent space launch country.

# **CHAPTER 6**

## **SPACE SYSTEMS ARCHITECTURE**

### **INTRODUCTION**

All space systems consist of a set of elements or components, the orderly arrangement of which defines the architecture. This chapter discusses the various elements that define a space systems architecture. Knowledge of this subject is important since it is fundamental to the overall understanding of any space program. For the military, space offers the particular advantage of achieving the ultimate high ground through a global perspective. However, space missions are hazardous and very expensive. Consequently, mission planners and systems designers must be cognizant of these fundamental limitations when procuring a system to assure we achieve the greatest return for the space investment. To maximize performance for the money spent, we must require of the system only what it can reasonably achieve. To accomplish this objective, we need to be familiar with the various elements that comprise a space systems architecture so we understand how they relate to each other and impact the overall mission.

### **ELEMENTS OF A SPACE SYSTEMS ARCHITECTURE**

Military space operations range from communication, to navigation, to observation. However, no single system can accomplish all these missions or can fully cover all contingencies. This is why the U.S. military has invested so heavily in its various space systems and will continue to do so in the foreseeable future. While our military objectives remain somewhat constant, the method of achieving these objectives changes as technology evolves. This process is reflected in the way in which a space systems architecture is designed and this design starts with defining mission objectives.

### **DEFINE MISSION OBJECTIVES**

All space missions start with a need or a requirement that can be best accomplished by going into space. The need creates the mission, which in turn, defines the space architecture necessary to make the system work. Designing an architecture is a costly, complex, and time consuming process that takes careful and deliberate planning to accomplish properly.

As a first step, broad goals the system must achieve are identified. These broad goals answer the question of why we are going into space. This process normally results in a mission statement that identifies the major objectives of the mission, the user, and the operation concept. Also identified in this phase is how well we intend to accomplish the objectives in terms of the limitations imposed by technology and cost constraints. This is an iterative process of defining

and refining both what has to be done and what mission concept will do it at the lowest cost. Eventually, another question “Does the system meet the user’s needs?” is answered.

Since using space assets is so expensive, cost is a fundamental limitation to nearly all space missions. Consequently, good mission objectives must incorporate user needs and characteristics such as global coverage that will be exploited to achieve them. Otherwise, it will probably be more cost-effective to accomplish the mission on Earth.

## **THE SPACE SEGMENT**

The space segment of the architecture refers to the spacecraft(s) which when placed in orbit will accomplish the mission. A spacecraft typically consists of two segments: a payload, which includes the hardware and software elements that perform the mission; and a spacecraft bus that supports the payload by providing orbital maintenance, power, command and control, temperature control, data handling, etc., to insure that the payload operates properly.

Space vehicles are complex, expensive systems operating in a harsh environment. To design a spacecraft requires a complete understanding of the mission, including the payload’s size and characteristics, plus significant system restraints such as orbit, lifetime, and operations. The design process involves identifying these functions and selecting the best approach for each function.

All spacecraft, regardless of mission, have similar subsystems that allow the vehicle to function. For example, without a communications subsystem, commands could not be processed, or without an electrical subsystem such elements as thermal and attitude control could not be maintained. It is through the subsystems that spacecraft receive the resources to function properly.

### **The Communications Subsystem**

The communications subsystem can link the spacecraft to the ground element or to other spacecraft in the same orbit. Data flowing from the spacecraft is called downlink, while data flowing from the ground element is called uplink, and data flowing between spacecraft is called cross link. These subsystems usually consist of a receiver, transmitter, and a variety of antennae. The data transmitted can be either satellite health and status information, commands, ranging, or mission data.

Since distances between orbiting spacecraft and ground stations typically vary between a few hundred to several thousand miles, unique engineering problems are created that need to be resolved to ensure that mission operators can communicate with the spacecraft. For example, because of the altitudes involved, the propagation of radio signals between the Earth and the spacecraft are affected by the ionosphere and the atmosphere. This causes both signal distortion, or noise, and attenuation. As a consequence the transmitted signal can be extremely

weak by the time it reaches a ground station. Receivers need to be designed to compensate for this limitation.

Also, receivers must be capable of calculating the doppler effect associated with a spacecraft. Except for those in geosynchronous orbit, spacecraft are usually moving at high rates of speed relative to the ground station. As a spacecraft appears above the Earth's horizon and comes into view of the ground station, the frequency of the received signal increases and then decreases as the spacecraft passes overhead and fades over the horizon.

Design of spaceborne communications equipment is also constrained by such factors as hardware and software capabilities, power requirements, size limitations, weight restrictions, reliability standards, and resistance to multiple types of radiation present in the space environment.

Additionally, different types of spacecraft require different types of antennae to perform the communications function. Spacecraft that maintain a stable attitude in space can utilize high-gain antennae that transmit/receive thin, pencil shaped beam signals. Spacecraft that spin however, are normally limited to omnidirectional or spherical beam shaped antennae. Spacecraft antennae are often large, but relatively delicate structures. Since they are mounted on the outside of the spacecraft, they are exposed to greater extremes of heat and cold, all of which must be considered during their design phase.

## **The Data Management Subsystem**

Data management is crucial to the operation of a spacecraft. Inadvertent errors in the performance of the data management subsystem can cause the abrupt termination of the mission or total loss of the spacecraft. To prevent catastrophe and sustain mission performance, data is processed in three different ways.

- **Command Processing.** Command Processing permits the spacecraft to be configured in response to commands transmitted from the ground station. Examples of these commands include applying or removing power from a system, altering operating modes, or uploading complete computer programs into the onboard memory.
- **Telemetry Processing.** Telemetry Processing enables data to be transmitted from the spacecraft to the ground station. Accurate and timely telemetry is required for system operators to determine the health and status of the spacecraft and take corrective action as necessary.
- **Data Processing.** Data Processing and Storage allows the communication system to interface with all the processors in the spacecraft through various kinds of input/output channels, or over the spacecraft data bus. These processors are designed to operate

autonomously to enable the spacecraft to perform its mission with minimum ground station control.

### **The Power Subsystem.**

The power subsystem provides all the electrical energy used by the spacecraft and is normally provided by three sources:

- Solar energy,
- Stored energy carried by onboard batteries, or
- A combination of the two.

The power system must be able to provide reliable power for all spacecraft loads. These loads include sophisticated spacecraft instruments, sensors, transmitters, and any mechanical device that requires power to operate. Since spacecraft loads are powered by electricity, the interface between the power subsystem and the other spacecraft subsystems is an electrical distribution system. This distribution system consists of power buses, wiring, load protectors, and connections.

Another source of electricity is from stored energy. This power source uses batteries and fuel cells, and is characterized by combining two chemical elements for a subsequent release of electrical power. All spacecraft employ batteries as power storage devices. Typically, the primary power producing system is used to charge the onboard batteries, and during times when power cannot be generated, draws this energy from the storage devices. If the main power source is based on solar cells, the batteries will charge when the spacecraft is in the sun, and then discharge when the spacecraft is in the dark. Batteries used for spacecraft applications are generally made of NiCd (nickel and cadmium) or NiH (nickel and hydrogen).

Fuel cells are an electrochemical device in which the chemical energy of a conventional fuel and oxidizer are stored external to a battery and are fed to it as needed. Fuel cells, because they consume both stored fuel and oxidizers, would generally not be considered for spacecraft missions of long duration. A simplified diagram of a gaseous hydrogen and oxygen fuel cell is shown in Figure 6-1. The disadvantage of both systems is they add a lot of weight to a spacecraft as compared to the amount of power produced.



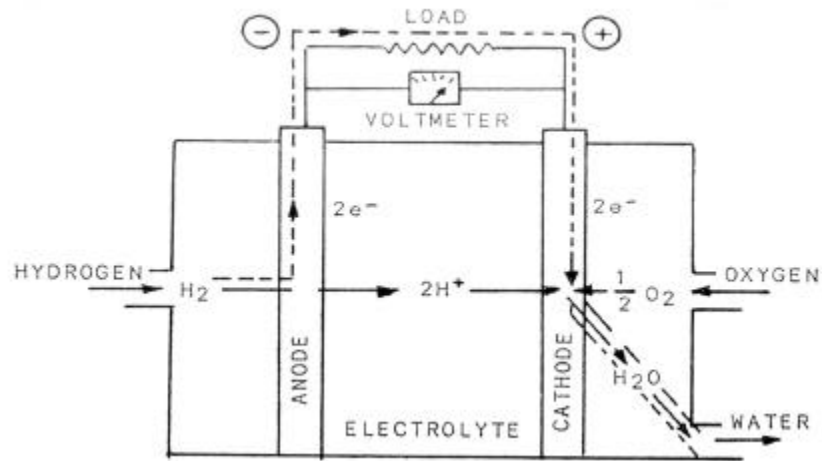


Figure 6-1. Simplified diagram of a gaseous hydrogen and oxygen fuel cell.

### Thermal Control Subsystem.

The thermal control subsystem keeps the thermal condition of a spacecraft within a specified range. High temperatures may cause electronic components to fail, and low temperatures may cause moving mechanisms or fuel lines to freeze. The thermal control system must be able to react throughout the environmental and operational configurations expected. As discussed in chapter 3, thermal control in space is difficult because of the space environment, which exposes spacecraft to extreme temperature differences. Spacecraft surfaces exposed to direct sunlight experience extremely high temperatures, while surfaces in the dark experience low temperatures. Low Earth orbiting spacecraft continuously cycle in and out of the Sun's radiations, absorbing and radiating energy in phases. Geostationary satellites may be exposed to or eclipsed from solar radiation continuously for weeks or months. Internally, a spacecraft may generate large quantities of heat during times of peak operation and little during dormant periods.

Thermal control devices fall into two categories, passive and active.

**Passive.** Passive devices simply shield, insulate, or change their thermal characteristics depending on the existing temperature of a satellite. The external coating of a spacecraft determines the craft's absorptivity (how much external energy is absorbed), and emissivity (how much internal thermal energy is radiated into space) characteristics to control temperature. An analogy to submarines is the anechoic coating on the surface of the submarine that is used to reduce the submarine's sound characteristics. Many spacecraft are wrapped in thermal blankets to retain internal heat, and some spacecraft are equipped with heat-activated louvers, which open or close to expose different external surfaces to radiate or retain internal heat.

**Active.** Active devices usually involve some sort of working fluid to carry heat from one location within the spacecraft to another. Refrigeration devices, electric heaters, heat pumps, and heat pipes are examples of active thermal control devices. These devices have the ability to more precisely control spacecraft temperatures, but their disadvantage is they increase weight and complexity.

### Attitude Control Subsystem

Depending on the mission, a spacecraft may have varying requirements for pointing accuracies. This is a function of the attitude control subsystem. Basically, a spacecraft must be able to determine its own attitude with respect to some reference, and be able to modify this attitude as necessary to perform a desired mission.

Attitude determination for a spacecraft involves three functions:

- Acquire position data relative to the spacecraft,
- Compute direction vectors to the reference system, and
- Compare attitude control sensor data to the reference direction vectors.

The process of determining the vehicle's attitude requires large numbers of computations. The computations can be performed by the spacecraft's ground segment, but normally this is accomplished on board the spacecraft itself.

The terms roll, pitch, and yaw are often used in discussions of attitude control. Yaw is measured toward the center of the Earth, roll is measured in the direction of a spacecraft's orbit, and pitch is measured perpendicular to the yaw-roll plane (See Figure 6-2.). The data necessary to control these conditions is accomplished through a number of different sensors. The data is then acted upon by various attitude control devices (mechanisms).

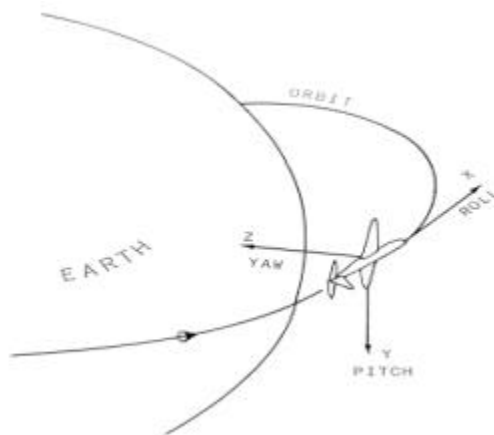


Figure 6-2 Graphical representation of roll, pitch, and yaw.

## Sensors

To acquire position data relative to spacecraft, the spacecraft must be able to measure its position relative to some object. The four types of measurement devices used for this task are Earth Sensor, Sun Sensor, Star Sensor, and Magnetic Field Sensor.

- **Earth Sensor.** An Earth sensor typically uses the Earth's infrared radiation (this is the radiation associated with the earth's temperature), to detect the contrast between the black cold void of space and the radiation from the Earth. The direction to the Earth's center can be inferred by two (or more) detectors sensing the Earth's edge at a substantial angular separation. Using this method, spacecraft at an altitude of 500 miles can measure pitch and roll angles to a 0.1-degree accuracy.
- **Sun Sensor.** Sun sensors typically use an arrangement of solar cells to measure sun-line angles. Generally, three to six sun sensors are mounted on the surface of the spacecraft, and the sun-line angles from these sensors are used to calculate the spacecraft's position relative to the sun.
- **Star Sensor.** In a typical star sensor, a space sextant measures the angle between two stars and a near body to determine two lines of position. A series of these measurements is made to secure an accurate position. There are two general categories of star sensors, star scanners, and star trackers. Star scanners are used on spinning spacecraft while star trackers are used on non-rotating spacecraft.
- **Magnetic Field Sensor.** Magnetic field sensors typically use a three vector magnetometer to measure the three components of the earth's magnetic field. These magnetometer measurements are combined with a math model of the magnetic field to determine the attitude of the spacecraft.

## Attitude Control Mechanisms

Now that you know some of the basic concepts and terminology of attitude control, let us discuss some of the more common methods used by operational spacecraft. The four commonly used mechanisms for establishing and maintaining attitude are:

- Gravity-gradient stabilization
- Spin stabilization
- Thruster control
- Reaction Wheel Control

## Gravity Gradient Stabilization

The gravity gradient technique uses the torque produced by slight differences in the direction and magnitude of the earth's gravitational field to orient a spacecraft. The origin of the gravity-gradient torque is shown in Figure 6-3, which is a sketch of a satellite consisting of two equal point masses,  $m_1$  and  $m_2$ , separated by a rigid massless rod of length  $l$ . As you can see, the gravity force on  $m_1$  is greater than the gravity force on  $m_2$  because  $m_2$  is further away from the Earth than  $m_1$ , and the moment arm of the gravity force on  $m_1$  is greater than the moment arm of the force on  $m_2$ . Therefore, for both these reasons, the net torque will tend to reduce the angle  $\theta$  to zero, establishing the spacecraft in a stable position.

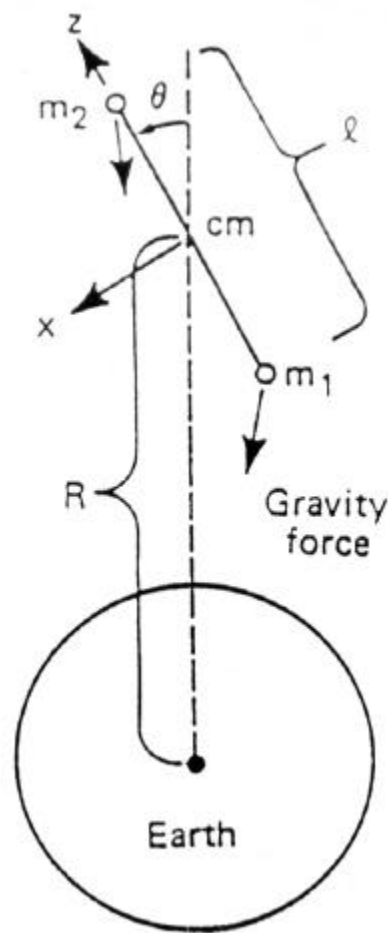


Figure 6-3. Origin of the gravity-gradient torque.

## Spin Stabilization

Spin stabilization uses the same principle as a gyroscope for stabilization. A spin-stabilized spacecraft tends to hold its spin axis orientation fixed in space. This attitude can be maintained for hours or days without control activity, which has important advantages for simplicity and reliability. For passive spin stabilization, the spin axis must be the principal axis of maximum moment-of-inertia. The reason for this is that spinning about any other axis is unstable; any disturbance may cause the spacecraft to move into a lowest energy position, which is aligned with the axis of maximum moment-of-inertia. Spinning about an axis of minimum moment-of-inertia is possible with active control of nutation, where nutation is the bobbing motion of the spin axis between inner and outer cones (see Figure 6-4). A very popular variation on spin stabilization is called dual-spin, one large section of the spacecraft is spinning and another large section is non-spinning (often referred to as "de-spun"). This scheme has many of the advantages of spin stabilization, where the large angular momentum of the spinning section tends to hold the attitude in space without rapid attitude control activity. The de-spun platform provides an ideal location for Earth pointing communication antennas.

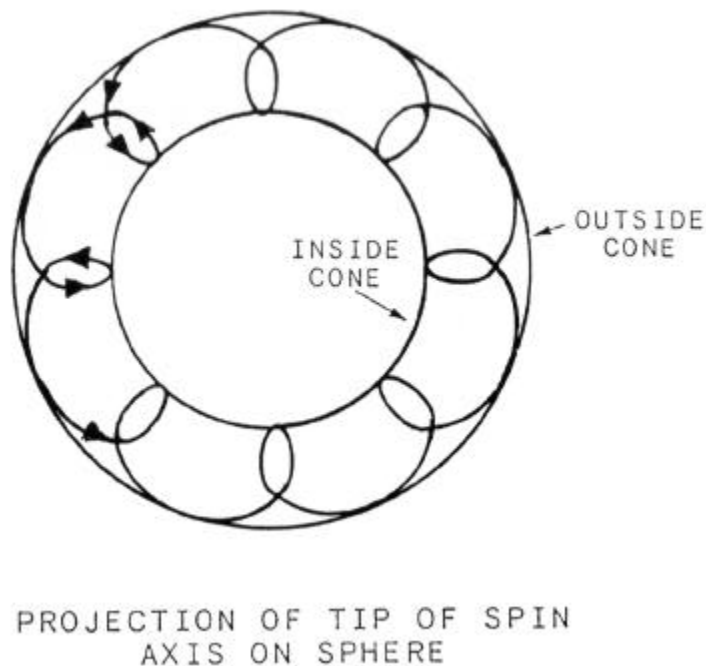


Figure 6-4. Spin axis between inner and outer cones.

## **Thruster Control**

The three-axis attitude control by thrusters is often used for attitude control on manned space vehicles (NASA's Space Shuttle is a good example). This method provides substantial control authority, and the ability to counteract large disturbance torques. In this method small nozzles, generally referred to as thrusters, are located at various positions on the spacecraft. The attitude of the spacecraft is controlled by firing these thrusters at the proper time, and for the proper duration.

## **Reaction Wheel Control**

A "reaction wheel" is an internal rotating device that exerts a torque on a spacecraft by the reaction effect (for every action, there is an equal and opposite reaction), as the rotating element is accelerated. The direction of the torque vector is parallel with the axis of wheel rotation. To produce a torque vector in an arbitrary direction in the body requires a minimum of three reaction wheels. Generally four or more wheels are used to provide component redundancy for the attitude control system. Reaction wheels take the place of the thrusters discussed in the previous section. They have the advantage that no mass is consumed, and the spacecraft will not suffer eventual loss of attitude control due to fuel depletion. The magnitude of the torque effect can be easily modulated over the range from zero torque to maximum by electronic control of the reaction wheel motor current. This makes it possible to design linear control systems with finer attitude performance control than can generally be obtained with thruster control. One of the major problems associated with this method is eventually the speed of one or more wheels may reach the physical limits of the drive electronics, or the structural limits associated with the wheel. If a wheel reaches its limit and further requests for acceleration cannot be satisfied, the wheel is "saturated," and the satellite is in danger of losing attitude control. Therefore, some means of "unloading" the wheels, i.e., getting them to run closer to zero, is necessary. The Hubble Space Telescope does its "unloading" by selectively energizing onboard electromagnets that interact with the earth's magnetic field to "unload" the reaction wheels.

## **Sources of Attitude Disturbance**

Because space is a vacuum, it would seem that the attitude of a spacecraft (once in its proper orbit) can easily be maintained. But space is not a perfect vacuum, and there are environmental factors that affect the attitude of a spacecraft. These factors include aerodynamic torque, solar radiation, magnetic field, and gravity gradient induced torque.

- **Aerodynamic Torque.** Aerodynamic torque is the result of the drag force from the Earth's atmosphere. The lower the altitude of a spacecraft, the larger the effects of atmospheric drag.

- **Solar Radiation Induced Torque.** Solar radiation induced torque is generated because light from the Sun produces a very slight pressure effect. At spacecraft altitudes above 600 miles, aerodynamic torque is small compared to solar radiation induced torque.
- **Magnetic Field Induced Torque.** Magnetic field induced torque is caused by permanent magnetization of spacecraft hardware components interacting with the Earth's magnetic field. Care must be taken in the design and construction of a spacecraft to minimize the magnetic effects of onboard components.
- **Gravity Gradient Induced Torque.** For spacecraft that are not gravity-gradient stabilized, the gravity-gradient effect is a source of attitude disturbance. Figure 6-5 shows a graphic representation of the torque spectrum for a spacecraft with a projected area of 25 square meters and masses  $m_1 = m_2 = 500$  kilograms separated by 25 meters. The tick marks on the graph represent the spacecraft's orbital altitude in kilometers.

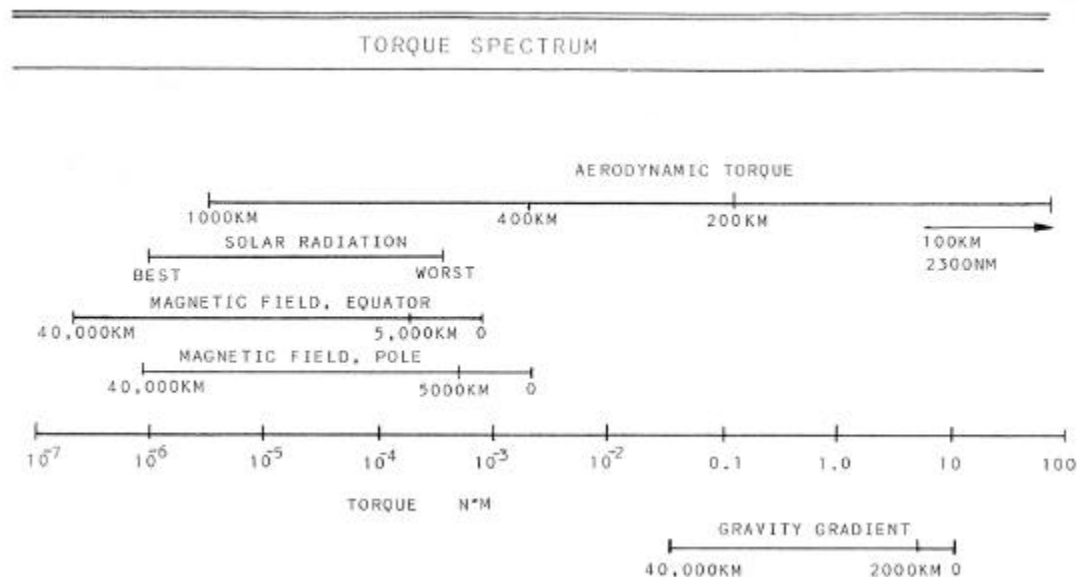


Figure 6-5 Graphic representation of the torque spectrum.

## THE GROUND SEGMENT

For each space system, there is a ground infrastructure manned by trained operators who provide management and control. During the design phase, studies are conducted to determine whether a function is best performed on board the spacecraft or by the ground segment. The capabilities and limitations in computational power, electrical power generation

and storage, and spacecraft weight requirements are considered. Functions inappropriate for execution by the spacecraft are incorporated into the ground segment.

A typical ground segment is made up of facilities, processes, data networks, computer hardware and software. A trained staff commands the spacecraft, monitors telemetry, and routes sensor data for appropriate utilization. Generic functions and processes of a typical ground segment follow.

### **Ground Segment Functions**

The management of the ground segment can range from managing a simple one facility operation, to managing a large network with international cooperation of control centers, sustaining engineering, and training facilities. In each case there exists three primary functions: program support, mission operations, and operations planning.

- **Program Support.** Program support provides the ground segment with all of the necessary administrative, operations coordination, and general technical support to sustain a mission.
- **Mission Operations.** Operations takes in data from numerous sources, charts the spacecraft course, plans the necessary commands, and executes them. Operations personnel working at a control center require a working knowledge of spacecraft systems, how to operate them efficiently, and how to bypass them when they malfunction. Flight controllers are usually assigned by specific disciplines, such as electrical power, mechanical systems, data management, attitude control, and for manned spacecraft, environmental control. A team of flight controllers is coordinated by a central control center director who has overall responsibility for the safety of the spacecraft (or crew) and the completion of its mission.
- **Operations Planning.** Operations planning determines how the overall program plan is to be implemented. For example, the precise time and duration of firing attitude control thrusters in order for the spacecraft to aim a spacecraft sensor at a particular spot on the Earth or in the heavens must be carefully planned. Planning information must be accumulated on the sensor, the target's location, spacecraft control systems, and the orbital trajectory before a determination is made how to construct the commands to execute the operation. Operations planning choreographs the flight controllers' activities so that each system or sensor is operated to maximize available resources (power or crew time), and to work with the other operating systems to meet the various mission requirements.



## **Commanding**

Command and control is the primary function of the ground segment. This function requires personnel to be in contact with the spacecraft, and deal with the spacecraft's operations, utilization, changes in configuration, and anomalies.

Through a communications network, space flight controllers send commands to the spacecraft which are then routed to the designated system or sensor. Some commands are sent from the ground for immediate execution by an onboard system (real-time commands). Additionally, commands can be stored onboard in computer memory for execution at a later time. These commands, which are normally referred to as stored program commands (SPCs), allow for autonomous operation. If commands are constructed or sent improperly, they could render a spacecraft useless. An example of improper commanding would be to fire attitude control thrusters in the wrong direction, at the wrong time or for an incorrect duration of time. This might cause:

- An undesirable rotation of the spacecraft
- Prevention of any further commands from being received by the spacecraft because spacecraft receive antennas are pointed in the wrong direction
- Positioning of solar arrays away from the Sun resulting in loss of spacecraft power

To avoid mistakes, commands sent to a spacecraft are reviewed and validated prior to their transmission. Command verification can be accomplished using a spacecraft simulator, where commands are sent to a ground representation or model of the spacecraft and the results monitored. Another validation method used is to compare commands to standardized or previously verified commands.

## **Tracking and Monitoring**

Tracking a spacecraft's position, and monitoring its health and status are critical factors in successful spacecraft operations.

Spacecraft tracking is required for navigation purposes, coordinating activities with ground stations, or coordinating any space-to-space activities. Tracking can be accomplished using ground radars when the spacecraft is within range, but this method cannot determine precise spacecraft attitude. Tracking can also be accomplished by downlink of the spacecraft's calculated navigational state and attitude. Whatever the means, it is imperative that the control center have up-to-date location and attitude information on the spacecraft.

Monitoring is accomplished by transmitting the onboard instrumentation data via the communications network to a control center. Once in a control center, the raw "downlink" data is reformatted into engineering units and routed to the appropriate flight controller displays.

Downlink data is stored and archived for later study of system operating trends, failure cause and effect investigations, or for scientific analysis.

## THE COMMUNICATIONS SEGMENT

The first regular military use of satellite communications occurred in the early 1960's when the Navy used the moon as a medium for passing messages between ships at sea and shore stations. This method of communications proved reliable when other methods failed. Today, spaceborne data relay and communication systems are essential for command and control in this era of global military operations.

As discussed in chapter 3, information is carried between the ground and space segments of a space system via electromagnetic waves. The information to be passed is impressed on these waves through modulation using various schemes. The type of electromagnetic wave, modulation technique, and the transmission power level are all important factors in establishing a successful communications link and is discussed below.

### Radio Wave Propagation

The electromagnetic spectrum is divided into different frequency bands, with radio and microwave bands being most commonly used for communication. Figure 6-6 shows how these bands are subdivided. Propagation properties and data carrying characteristics vary with frequency band.

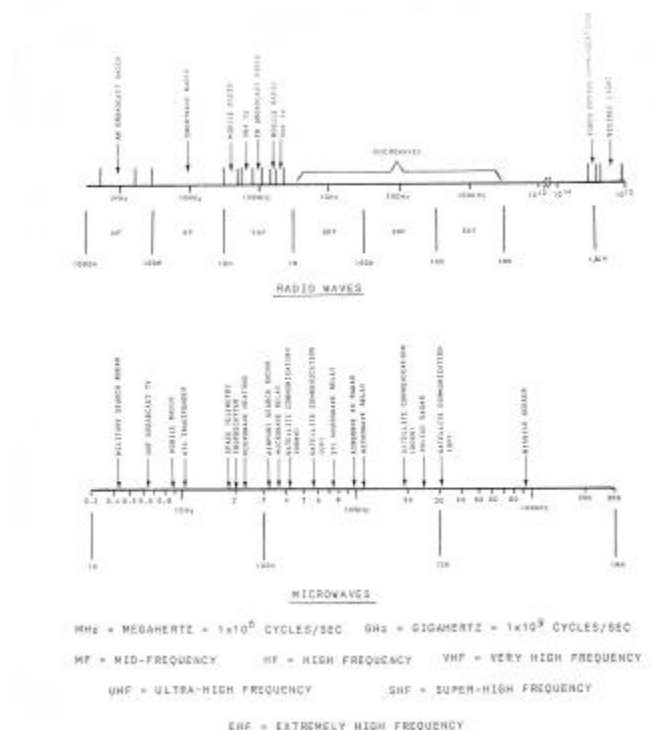
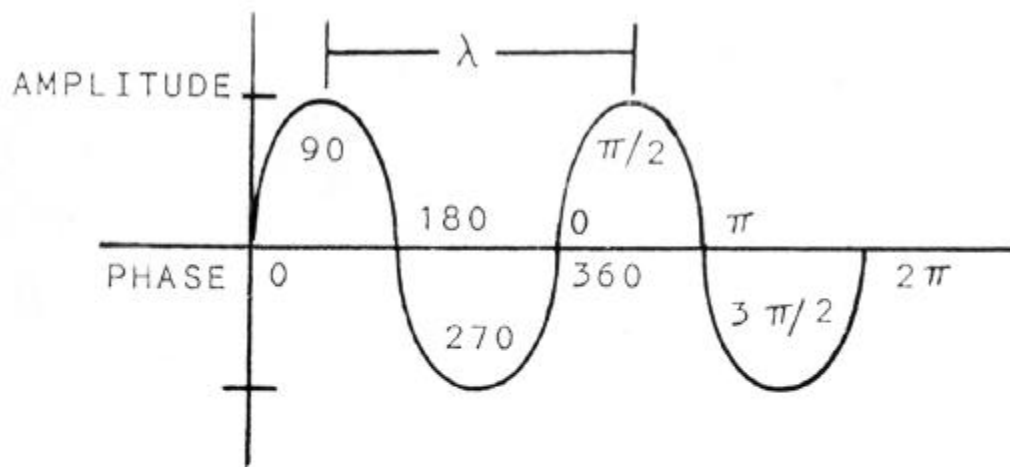


Figure 6-6. Communications bands.

A generic electromagnetic wave is described in Figure 6-7. Frequency, amplitude, and phase are all important factors in communications. There are four types of electromagnetic waves, known as carrier waves, used for communications. (See Figure 6-8.)

- Direct wave
- Ground wave
- Sky wave
- Space wave



$$\begin{aligned} \lambda &= \text{WAVELENGTH} \\ \text{M} &= \text{METERS} \quad \mu = \text{MICRONS} = 10^{-6} \text{ M} \\ f &= \text{FREQUENCY} = c/\lambda \quad c = 3 \times 10^8 \text{ M/S} \\ &\quad \text{CYCLES PER SEC (Hz)} \\ \omega &= \text{ANGULAR FREQUENCY} = 2\pi f \\ &\quad \text{RADIAN PER SEC (RAD/SEC)} \end{aligned}$$

Figure 6-7. A generic electromagnetic wave.

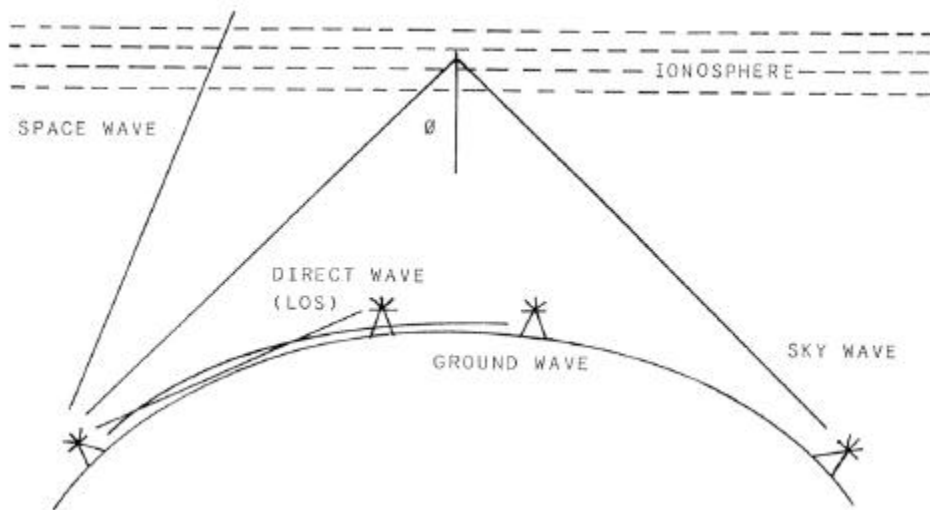


Figure 6-8. Types of electromagnetic waves.

### Direct Wave

Direct waves travel from the transmitter to the receiver along a direct, unimpeded path. This is known as line of sight communications, and almost any frequency can be transmitted in this manner. Direct wave communications have limited range.

### Ground Wave

At frequencies less than a few megahertz, electromagnetic energy can interact with the material in the Earth. Such waves tend to follow the contour of the Earth's surface. Ground waves can communicate over longer distances than direct waves, but the amount of information transmitted is limited.

### Sky Waves

Frequencies higher than AM frequencies cannot propagate as ground waves, but may interact with the ionosphere. This type of interaction causes the electromagnetic energy to be refracted back toward the receiving station on the ground. Communications via sky waves can achieve very long ranges, essentially providing worldwide coverage.

## **Space Waves**

Above the critical frequency (generally above 30 Mhz), electromagnetic waves are not affected enough by the ionosphere to create sky waves. Communications using these frequencies must be LOS (line of sight) between a transmitter/receiver located on the Earth and a transmitter/receiver located in space.

## **POWER BUDGET**

The amount of power an antenna delivers to a receiver, and the ability of the receiver to pick up the signal determines if successful communications will occur. The power (or link) budget analysis of the system evaluates the probability of successful communications. The power budget analysis takes into account transmitter power, transmitting antenna gain, receiving antenna gain, free space loss, and losses caused by spreading and incidental loss. Miscellaneous loss depends upon the environment through which the signal will pass. For example, communications using microwave frequencies are greatly hampered by rain showers or thunderstorms.

## **Noise**

The amount of power received may still not determine if the receiver will understand the transmitted information. The reason for this is the presence of noise which can interfere with the transmitted signal. Noise is caused by the transmitting and receiving equipment, and natural sources such as the Sun, Earth, and atmosphere, as well as other celestial bodies.

## **Signal To Noise Ratio**

Successful communication systems, commonly referred to as links, are designed to operate under all expected conditions of losses and noise. The measure of this is given by a receiver's signal to noise ratio:

$$\text{S/N ratio} = \text{Power/Noise}$$

A receiver will have a minimum signal to noise ratio specified for acceptable operation. If the received power decreases, or noise increases such that the actual signal to noise ratio is less than the minimum specified, the modulated signal may not be intelligible or detected at all.

## **Modulation**

Modulation is the means by which information is impressed on electromagnetic radiation. There are two major components to a communication signal. They are the baseband signal and the carrier wave.

## Baseband Signal

The baseband signal is the information to be transmitted. There are two forms of baseband signals: analog and digital.

- **Analog.** Analog signals are the raw, continuous wave-like frequencies of sound or light. Television stations transmit analog signals that are used by a TV set to illuminate the tube in a certain way to produce a picture.
- **Digital.** Digital signals are in the form of a string of 1's and 0's, which represent the original information and allow easier or faster data transmission.

## Carrier Waves

Carrier waves are electromagnetic signals used to carry the baseband information between transmitter and receiver and are chosen for their propagation characteristics with due regard to the amount of baseband information to be transmitted. They are used because the baseband signal may not have sufficient propagation characteristics for successful communication. A carrier wave can normally only be impressed with baseband frequencies up to about 10% of the carrier wave frequency.

## General Modulation Techniques

Baseband information is impressed onto a carrier wave for propagation between stations. In all cases some characteristic (amplitude, frequency or phase) of the carrier wave is modified to represent the baseband information whether it is in analog or digital form.

- **Amplitude Modulation (AM).** In amplitude modulation, the baseband signal is used to change the amplitude of the carrier wave in such a way as to represent the baseband information. Frequency and phase are held constant.
- **Frequency Modulation (FM).** In frequency modulation, the amplitude and phase of the carrier wave are held constant, while the frequency is modified by the baseband signal. The frequency variation from the known carrier wave is directly proportional to the frequencies of the baseband signal.
- **Phase Modulation (PM).** In phase modulation, information is impressed upon the carrier signal by using the baseband signal to modify the phase of the carrier wave. Phase modulation is not used much in conventional (analog) communications, but is widely used in digital communication.

- **Pulse Modulation (P-M).** In this modulation technique, the modulated carrier signal is sent in a series of discrete pulses. The height, width, or position of the pulses is altered in a definite pattern corresponding to the information being transmitted. Pulse Amplitude Modulation (PAM) is very similar to AM. Pulse Width Modulation (PWM) mirrors FM in that the width or duration of each pulse varies in direct proportion to the value of the modulating wave. Pulse Position Modulation (PPM) resembles PM in that the amplitude and width of the pulse are kept constant, but the position of each pulse in relation to the position of a recurrent reference pulse, is varied. Pulse Code Modulation (PCM) refers to a system in which values of a "quantized" modulating wave are indicated by a series of binary coded pulses. This will be further explained in the section on digital communications.

## **Demodulation**

Demodulation is the recovering of the baseband signal from the received modulated signal. The basic process simply uses the opposite of that used to modulate the carrier signal in the first place.

The demodulation process is made complicated because the received signal is usually weakened due to various losses, and because the information may have been corrupted during transmission.

## **DIGITAL COMMUNICATIONS**

Digital communications offers some benefits over analog in the areas of transmission, reception, and handling techniques.

Digital signals represent the original information using a binary coding system. In this system, strings of 1's and 0's are used to represent letters and numbers. Each individual 1 or 0 is known as a bit and 8 bits are known as a byte. A word is the standard unit in a binary coding system. Information is obtained by properly decoding the words of the binary coding system.

## **Analog to Digital (A/D) Conversion**

How can an analog signal, like music or a voice, be accurately converted into a digital signal? This question will be answered in the following section. Figure 6-9 shows a sinusoidal analog signal being digitized. Let's examine the main aspects, quantization, sampling, and transmission rate of this digitization process.

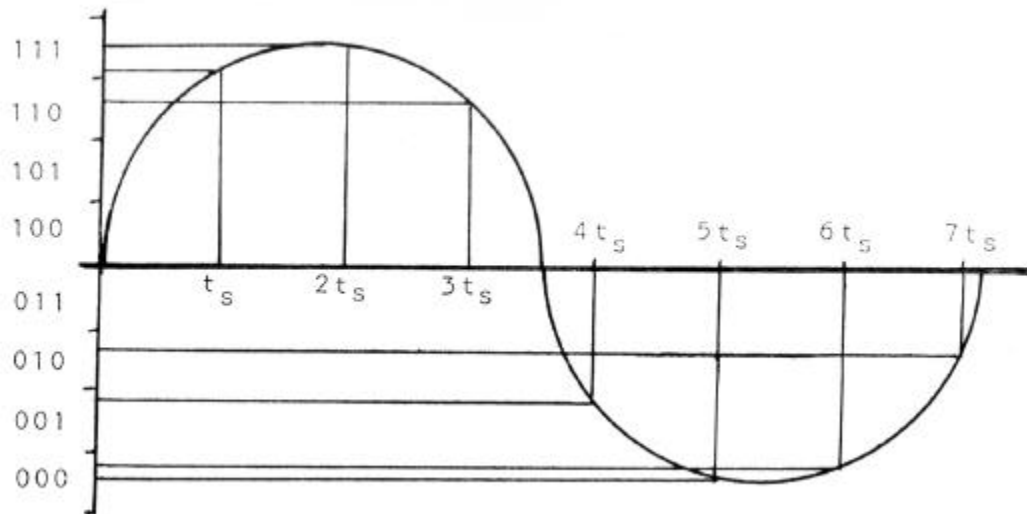


Figure 6-9 Sinusoidal analog signal being digitized.

- **QUANTIZATION.** Quantization is the method of assigning a range of digital values to represent the original analog signal. The quantization process has two limiting factors which are (1) the range of the analog signal value and (2) the number of bits available in the digital system.

The signal shown in Figure 6-9 has been split into eight quantization levels, known as Q-levels. There are limits to the number of bits a system can manipulate, so the signal should be represented with as few bits as possible. The method of assigning a particular bit word to each quantization level is called coding. Figure 6-9 has been split into eight Q-levels, and eight different three-bit words are assigned in specific order to each level. The word 000 has been assigned to the bottom level and a binary 1 added for each subsequent level.

- **SAMPLING.** The frequency at which a signal is assigned a quantization level (sampled) is called the sample period ( $T_s$ ). The signal is sampled often enough to allow the receiver to reconstruct the original signal from the digital information.
- **TRANSMISSION RATE.** The transmission rate represents the number of bits per unit time a digital system transmits, and is a measure of the capability of the system to pass information. The major limiting factor to transmission rate is the carrier wave's ability to transport digital information. Most spacecraft use digital communication methods, and in many cases, the transmission rate is a major limiting factor of the space system's capabilities.



## Digital Baseband Signals

The output of an A/D converter is a string of 1's and 0's representing the bits assigned to each successive sample of the original analog signal, and is usually represented by an output voltage where high voltage is a 1 and low voltage is a 0. The time the specific voltage is held to represent each bit is called the bit period ( $T_b$ ). The pattern of 1's and 0's is the information to be transmitted, and will be used as the baseband signal to modulate the carrier wave.

## Digital Modulation Methods

Digital modulation is a type of pulse modulation where the pulses are of equal amplitude and duration, and the information is transmitted by encoding the spacing between pulses as they are sent in sequence. There are three basic digital modulation techniques:

1. Amplitude Shift Keying (ASK)
  2. Frequency Shift Keying (FSK)
  3. Phase Shift Keying (PSK)
- **AMPLITUDE SHIFT KEYING (ASK).** In this modulation technique, the carrier wave is either transmitted, or not transmitted each bit period. The relationship between the carrier wave, baseband signal, and resulting ASK signal is shown in Figure 6-10.

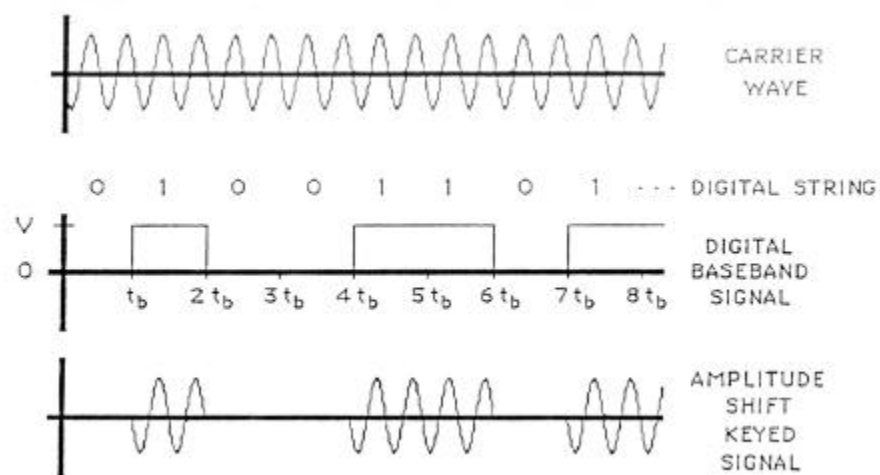


Figure 6-10. Relationship between the carrier wave, baseband signal, and resulting Amplitude Shift Keying (ASK) signal.

- **FREQUENCY SHIFT KEYING (FSK).** In this modulation technique, two carrier frequencies are used to represent a transmitted 1 and the other a transmitted 0. The relationship between the baseband signal and resulting FSK signal is shown in Figure 6-11.

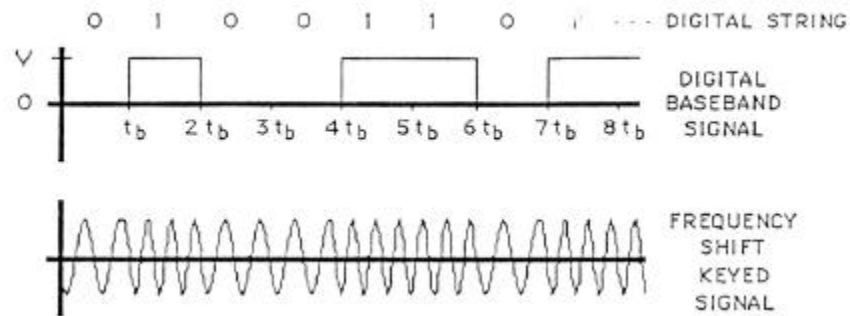


Figure 6-11. Relationship between the baseband signal and resulting Frequency Shift Keyed (FSK) signal.

- **PHASE SHIFT KEYING (PSK).** In this modulation technique, a change in a bit state is indicated by a change in the phase of the carrier wave. The relationship between the baseband signal and the resulting PSK signal is shown in Figure 6-12.

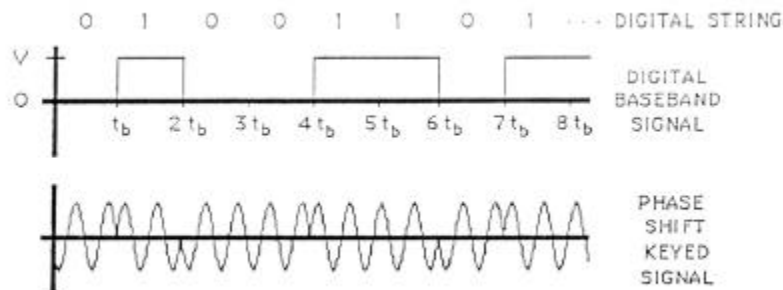


Figure 6-12. Relationship between the baseband signal and the resulting Phase Shift Keyed (PSK) signal.

An important point in PSK systems is to ensure that the receiver knows the starting bit, otherwise the reconstructed digital string will be opposite to the transmitted string. This is usually done by first sending a code that will indicate what the first bit in any message should be.

## Digital Demodulation

For digital demodulation, the demodulator must only detect the presence of a transmitted 1 or 0, which is much simpler than the analog demodulation task of recovering the actual analog baseband signal. This allows digital communications systems to obtain a successful link with lower minimum signal to noise ratios.

## COMMUNICATIONS SYSTEMS

Communications systems consist of a network of transmitters and receivers. Block diagrams of the major components of a transmitter and a receiver are shown in Figure 6-13.

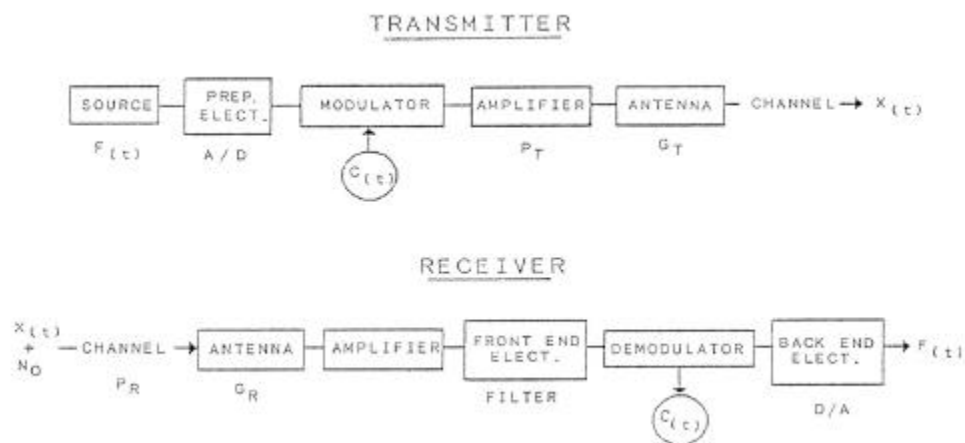


Figure 6-13. Block diagrams of the major components of a transmitter and a receiver.

### Transmitter

In the transmitter, the source represents the originator of the information signal ( $F(t)$ ). It may be a microphone of a radio or telephone; a video receiver of a television camera; or an antenna of a remote sensor. The function of the source is to turn information into an electromagnetic signal suitable for transmission. If the signal is to be digitized, an A/D converter would be part of the preparatory electronics that makes the signal ready for modulation onto the carrier wave. This takes place in the modulator. The amplifier boosts the signal to the desired transmit power ( $P_T$ ) and delivers it to the antenna, which produces the electromagnetic signal ( $X(t)$ ) for propagation. The channel represents the medium through which the signal travels between stations. In space, the channel is a vacuum.

## **Receiver**

On the receiving end, the antenna picks up the signal and its associated noise from the channel. Since the power level received is usually quite low compared to the transmitted signal, it is delivered directly to an amplifier to boost the signal strength. The front end electronics filters out some of the noise. The signal then goes to the demodulator where the baseband signal is recovered from the carrier wave. Finally, the back end electronics reproduces the transmitted information into its original form. It is here where the digital to analog (D/A) converter reconstructs the original message.

## **THE LAUNCH SEGMENT**

Given mission requirement, constraints, and a myriad of other factors, a decision must be made on which launch system configurations can deliver the spacecraft to its mission orbit by attaining a certain position in space with a certain velocity.

The launch process can severely constrain spacecraft design. Primary restrictions are the launch vehicle's lift capability and the environment to which it subjects the satellite on ascent. A launch system consists of a basic launch vehicle incorporating one or more stages and an infrastructure for ground support. It provides the necessary force to displace the spacecraft. Ultimately, it places the payload into the desired orbit with a functional spacecraft attitude. The term payload includes all hardware above the launch-vehicle-to-spacecraft interface, excluding the payload's protective fairing, which is usually part of the launch system. Thus, the launch-vehicle payload consists of the entire spacecraft and the booster adapter.

The booster is the rocket we see sitting on the pad during countdown. It provides the necessary change in velocity to get the spacecraft into space. The booster blasts almost straight up to gain altitude rapidly and get out of the dense atmosphere which slows it down through drag. Then it begins to pitch over to start gaining horizontal velocity.

Because of the limits of rocket technology, we can't construct a single rocket which can deliver a spacecraft efficiently into orbit. Instead, a large booster is actually a series of smaller rockets which light and then burn out in succession, each one handing off to the other like runners in a relay race. These smaller rockets are called stages. In most cases, a booster will require at least three stages before reaching orbit.

Normally, the booster can't deliver the spacecraft to its final orbit by itself. Instead, when the booster finishes its job and burns out, the spacecraft remains in a parking orbit. A parking orbit is a temporary orbit where the spacecraft will stay until transferring to its final mission orbit. Once a spacecraft is in its parking orbit, a final "kick" must send it onto a transfer orbit and, eventually, on up to its final mission orbit where it starts to perform its mission.

The extra kick of energy needed to transfer from the parking orbit to the final orbit comes from the upper stage. In some cases, the upper stage is actually integral to the spacecraft itself, sharing the plumbing and propellant which the spacecraft will later use to orient itself and maintain its orbit. In other cases, the upper stage is an autonomous spacecraft with the one-shot mission of delivering the spacecraft to its final orbit. In the latter case, the upper stage breaks off once its job is done. Regardless of how it is configured, the upper stage consists mainly of a rocket engine (or engines) and the propellant needed to change the spacecraft's energy enough to enter the desired final orbit.

Once the spacecraft reaches its final orbit, it may still need thrusters to keep it in place or maneuver around. Thrusters are relatively small rockets used to adjust the spacecraft's orientation (which changes over time from external forces) and to help maintain the orbit size and shape.

## **THE USER SEGMENT**

The user segment consists of the individuals and organizations that use data generated by a space segment in support of their missions. The user segment usually consists of multiple users spread over large geographic areas, but could be a single individual with a dedicated receiver performing a special operations mission.

## **USER ACCESS METHODS**

The ground, communications, and space segments are easy to define and describe. They are concrete physical entities with well defined functional elements. The user segment is more abstract, and each users' set of requirements are unique. To simplify our discussion of the user segment, we will use the type of access or interface that users have with a particular space system. These interfaces are as follows:

- **Direct Access.** The user receives space system information directly from the space segment
- **Indirect Access.** The user receives the space system data from an intermediate source

### **Direct Access**

A GPS equipped aircraft that receives navigational information directly from the GPS constellation is a direct user. As long as the aircraft is within view of sufficient GPS spacecraft and the onboard receiver is working properly, the pilot will have extremely accurate navigational data at his/her disposal. The pilot needs to take no action (except for turning on the GPS receiver) to access the information, so the fact that GPS is a space-based navigation system is transparent to the pilot.

## **Indirect Access**

A carrier battle group staff that receives satellite imagery data from some shore-based distribution point has indirect access. For example, LANDSAT spacecraft provide multi-spectral imagery of the entire Earth's surface. A battle group staff planning an amphibious operation would find this information very useful to determine soil composition and vegetation density of the planned beachhead. Because LANDSAT data requires considerable processing before it can be used by planners, this processing takes place at only certain locations. Therefore, LANDSAT data has to pass through many hands before it is available to tactical planners (see chapter 7).

## **ACCESS METHODS EVALUATION**

What are the important characteristics that must be evaluated before deciding whether to use direct or indirect access? Some of these important characteristics are timeliness, quantity of data, quality of data, ease of use, cost, and security. Direct access is usually more timely, has more data, the capability for better quality data, is harder to use, costs more, and has higher security risks than indirect access.

Mission requirements are generated by the user, whereas operational and systems requirements are generated by the supplier. From the user's viewpoint, the space system should provide a full data stream in real time directly to him at any location in the world. From the supplier's viewpoint, the space system should be built and operated at the lowest practical cost, with sensitive data protected from falling into the hands of an adversary. The space system that is fielded is usually a compromise between the users and the suppliers viewpoints after careful examination of the system, mission, and operational requirements.

System compromise is illustrated as follows. As mentioned earlier, a GPS equipped aircraft is an example of a direct user. The safe navigation of an aircraft in restricted airspace is a real-time problem, where the pilot must have a continuous stream of accurate navigation data. This user must have direct access to the space segment's data in order to fulfill his/her mission. The carrier battle group's staff on the other hand has indirect access to satellite multi-spectral imagery data. The staff needs timely access to the data, but it doesn't have to be in real-time. Moreover, security restrictions must be applied to the dissemination of satellite imagery data. The security of this data is best achieved by using indirect access.

For a given space system, the user segment can be a mixture of direct and indirect users. An example of this could be a space-based environmental monitoring system where one group of users doing weather prediction requires direct access, while another group of users doing climatic research only needs indirect access. Again the main point to remember is that the choice of user access method is a logical compromise consistent with satisfying the user's mission requirements.

## **SUMMARY**

Development of space system architecture is a complex, expensive, and time-consuming process. Although the most appropriate solution must meet mission requirements, political, legal, economic, and technical issues all need to be addressed in the overall planning of any space system. This process must lead to a detailed, well-defined mission concept that thoroughly justifies a space-based asset.





# **CHAPTER 7**

## **NAVAL TACTICAL USE OF SPACE**

### **INTRODUCTION**

This chapter provides an overview of the space systems and their related surface segments of most interest to the Navy and Marine Corps. These sections are organized into the functional areas of space-based force enhancements:

- Communications (command and control)
- Space-based warning
- Space based positioning and navigation
- Space-based Intelligence, Surveillance, and Reconnaissance
- Meteorological Monitoring
- Space-Based Environmental Monitoring

Each of these sections presents the space fundamentals involved and the major systems and constellations currently being used to provide these capabilities to the naval warfighter.

### **MILITARY SATELLITE COMMUNICATIONS SYSTEM (MILSATCOM)**

The Military Satellite Communications System (MILSATCOM) includes Ultra-High Frequency (UHF), Super-High Frequency (SHF), and Extremely-High Frequency (EHF) capabilities. Its role is to provide reliable, secure communications in support of Department of Defense (DoD) Command, Control, Communications, Computers, and Intelligence (C<sup>4</sup>I) in all levels of conflict, in accordance with the current national military strategy. Figure 7-1 displays the varied SATCOM frequencies found in the electromagnetic (EM) spectrum. MILSATCOM offers the naval commander some unique advantages. Those advantages include:

- Worldwide coverage
- Service to isolated areas
- Rapid expansion to new locations
- Reliable communications which exceed the range of line-of-sight (LOS) systems

Since all current MILSATCOM constellation life cycles terminate between 2003-2007, each of the constellations must have some type of a “gapfiller” or “transition spacecraft” to bridge between today’s UHF, SHF, and EHF constellations, and those that are predicted in 2010. Basically, a critically tight timeline exists to plan, budget, and prepare for the replacement and/or replenishment of those different satellite constellations and terminal systems.

## SATCOM Frequencies In The Electromagnetic Spectrum

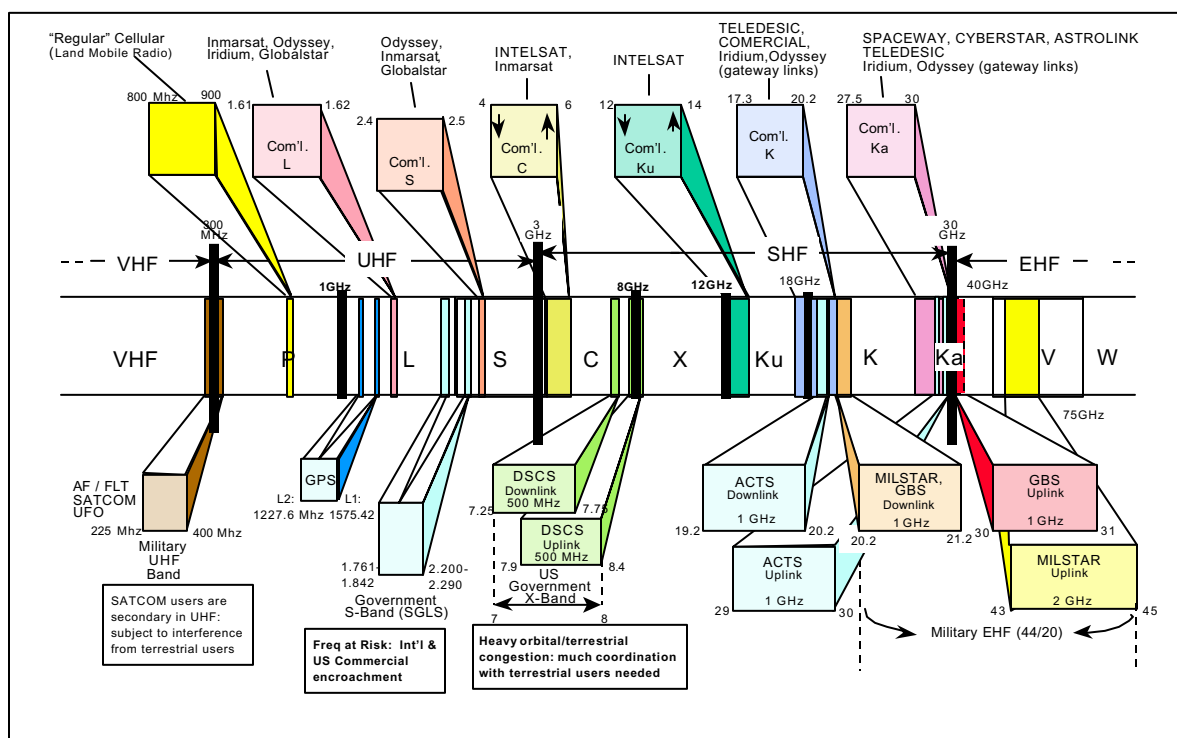


Figure 7-1. SATCOM Frequencies in the Electromagnetic Spectrum.

### NETWORK-CENTRIC WARFARE, GCCS, JTACS

As economic issues, business, and information technology evolve, so must our military. We are in the midst of a revolution in military affairs (RMA). Chief of Naval Operations Admiral Jay Johnson has called it “a shift from what we call platform-centric warfare to something we call network-centric warfare.” This metamorphosis will be the most important RMA in the past 200 years.

The naval warrior is moving out of the industrial age, one of weapons and material technology and into the information age, with information as both the weapon and the objective. Information dominance is seen as our ability to rapidly derive, protect, transmit, and employ information in a data-intensive battle space, while denying the enemy access to his own information infrastructure. This dominance implies an information focus, rather than a weapon focus with an information interest. Information dominance requires the naval warrior to use

information as a weapon, as an asset, and as a resource to be employed and refined.

The new dynamics of competition in both the modern economy and the military are based on increasing returns on investment, competition within and between ecosystems, and competition based on time. Information technology (IT) is central to each of these. There are two ways that network-centric warfare has the power for potentially increasing returns on investment. Very high and accelerating rates of information have a profound impact on the outcome of our forces, locking out alternative enemy strategies and locking in success:

- Network-centric warfare allows our forces to develop speed of command
- Network-centric warfare enables forces to organize from the bottom up — or to self-synchronize — to meet the commander's intent

Network-centric warfare derives its power from the strong networking of a well-informed but geographically dispersed force. It is composed of the information grid which ties together the sensor grid (radar, space, acoustic) and the engagement/shooter grid (ships, aircraft, ground armor, submarines, marines). The information grid will overlay the engagement grid of weapons system and a sensor grid of weapon sensors and sensor systems, creating the three dimension of the “battlecube.” Figure 7-2 illustrates the way in which all components work together.

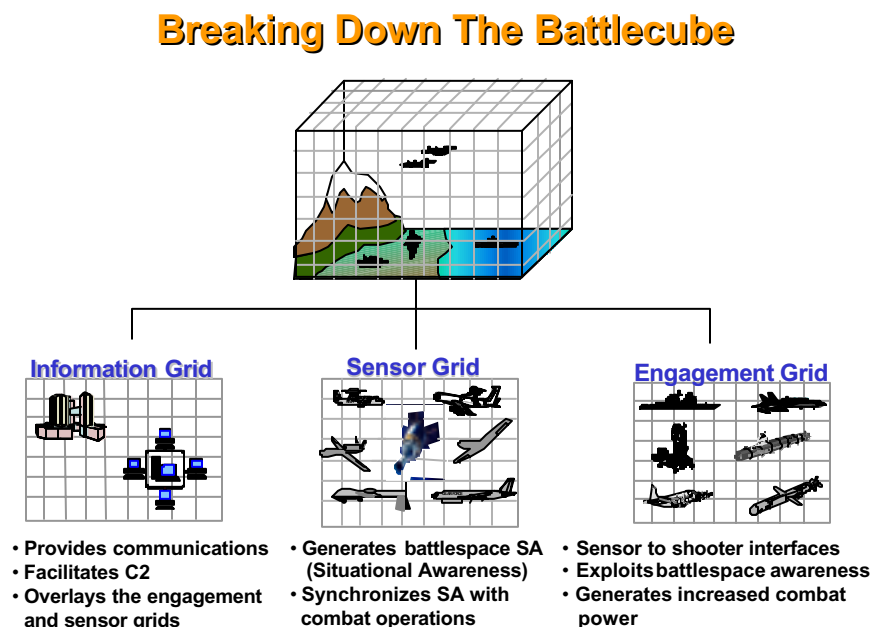


Figure 7-2. The Battlecube.

The enabling elements of network centric warfare are:

- A high-performance information grid
- Access to all appropriate information sources
- Weapons reach and maneuver with precision and speed of response
- Value-adding command-and-control ( $C^2$ ) processes (to include high-speed automated assignment of resources to need)
- Integrated sensor grids closely coupled in time to shooters and  $C^2$  processes

Our decision to fight on a network-centric rather than platform-centric basis requires change in the way we train, how we organize, and how we allocate our resources. A good understanding of our competitive space, therefore, is vital to achieving success. The Navy, indeed all services, must make these strategic decisions to maximize future combat power and relevance. Because a network-centric force operates under a different, more modern rule set than a platform-centric force, we must make fundamental choices in at least three areas:

- Intellectual capital
- Financial capital
- Transformation Process

Intellectual capital simply means the importance of the warfighter to understand the true force of his/her combat power in such things as Cooperative Engagement Capability (CEC), Global Command and Control System (GCCS), and Link-16. Information-based processes are the dominant value-adding processes in both the commercial world and the military. The services must both mainstream and merge those with technical skills and those with operational experience in these areas.

Financial capital is crucial in powering the Revolution of Military Affairs (RMA). Delays will mean higher costs, reduced combat power, and failure to achieve the concepts of Joint Vision 2010. The Navy's umbrella strategy for enabling the IT elements of network-centric warfare is Information Technology for the 21<sup>st</sup> Century (IT-21). It provides for accelerated implementation of customer-led command, control, communications, computers, and intelligence ( $C^4I$ ) innovations and existing  $C^2$  systems/capabilities (programs of record). For the fiscal year 1999 budget request and the Future Years Defense Program, Navy funding for IT-21 related programs exceeds \$2.5 billion.

Transformation Process describes the need for a process of co-evolution among technology, organization, and doctrine in the acquisition of network-centric warfare. The main objective is to create an ethos for experimentation, innovation, and a willingness to risk across the force, instead of a small sample group. Specific top-down experimentation will be required because of cost and size or to establish overarching priorities, but these are expected to spawn experiments from the bottom up and facilitate cultural and organizational changes. That is the concept behind the

Navy's Fleet Battle Experiment Program.

Finally, it is important to realize that network-centric warfare operation concepts, shifting competitive spaces, changing underlying rule sets, and co-evolution are not mere theories. They are real methods that have been already applied and will continue to help expand and strengthen our armed forces in a new century of change.

### **GCCS (Global Command and Control System)**

Through the next decade, Navy will move into network centric warfare through aggressive employment of the Global Command and Control System (GCCS), and the IT-21. These innovative programs seek to build a backbone of GCCS service to every ship in the naval force for passing tactical information and message traffic, linking command and control terminals, and providing Secret Internet Protocol Router Network (SIPRNET) access to all war fighters.

This network of GCCS to all ships has been accomplished through the use of INMARSAT-B (International Mobile Satellite) capability, an upgrade of INMARSAT-A. With INMARSAT-B, ships possess enhanced digital service and lower per-minute charges; with up to 64 Kilobits per second data rates.

In the future, the GCCS backbone and the information grid will be implemented using high-data-rate, wideband SHF SATCOM. The Defense Satellite Communication System Service Life Enhancement Program (DSCS-SLEP), the GBS (Global Broadcast Service), and commercial wideband systems such as Challenge Athena III will pick up much of the GCCS network load.

In less than five years, commercial SATCOMs will also be available that provide the truly networked capability Navy requires to implement a high-bandwidth, network centric warfare-focus. Emerging commercial systems, such as Teledesic or Celestri, will allow very high capacity communications in a three-dimensional network fashion for global naval support.

### **JTAGS (Joint Tactical Ground Station)**

The Theater Event System (TES) is the United States Space Command (USSPACECOM) architecture to provide reliable, comprehensive tactical warning support (assured warning) to theater. JTAGS is one of the three systems that have similar tactical support missions used by USSPACECOM to coordinate tactical warning. The three programs together make up the TES and mutually support each other in the mission of tactical missile and other event reporting to theater.

JTAGS is the transportable in-theater element of USSPACECOM's TES. It provides Theater Commanders a continuous 24 hour capability to receive and process in-theater, direct down-linked data from Defense Support Program (DSP) sensors in order to disseminate warning, alerting, and cueing information on Tactical Ballistic Missiles (TBM), and other tactical events of interest throughout the theater using existing communication networks.

The JTAGS processes data from up to three DSP satellites to determine launch points, state vectors, and predicted ground impact points for TBMs. JTAGS then ties directly to

worldwide and theater communications systems to immediately disseminate this critical information. JTAGS supports all Theater Missile Defense (TMD) pillars (attack operations, active defense, passive defense, and battle management/command, control, communications, computers, and intelligence (BM/C<sup>4</sup>I).

The key to JTAGS theater support is its direct connectivity and distribution architecture, via a variety of voice and data networks. Event data is received directly from DSP satellites covering the theater Area of Responsibility (AOR), is processed in-theater, and is disseminated to both theater and worldwide users by data and voice. By its in-theater location, JTAGS reduces the possibility of single-point failure in long-haul communications architectures.

Enhancements and improvements are planned for JTAGS that will significantly increase capabilities to support the warfighter. Some near-term developments are:

- Enhancements to accuracy, timeliness, and connectivity.
- Joint Tactical Intelligence Distribution System (JTIDS) integration--providing direct sensor-to sensor connectivity and improved theater TBM report dissemination timelines.
- Connectivity through the SIPRNET, GCCS, GBS, and other means.
- Capability to fuse DSP data with TBM data from sensors such as Cobra Ball, Airborne Warning and Control System (AWACS), JSTARS, etc. improving cueing to Active Defense and accuracy of the predicted ground impact point (PGIP).

A long-term goal of JTAGS is the transition to the Mobile Multi-Mission Processor (M3P) concurrently with the replacement of DSP satellites with Space-Based Infrared Sensors (SBIRS) satellites. M3P will have the same theater mission as JTAGS and also have strategic mission capability and mission requirements.

## **NAVAL SATELLITE COMMUNICATION SYSTEMS**

A primary objective of the Naval Telecommunication System is to provide worldwide communications to support Navy and Marine Corps command and control functions for the Department of the Navy. A variety of transmission media, including UHF SATCOM, SHF SATCOM, and EHF SATCOM are used in fulfilling naval communications requirements. UHF, SHF, EHF, Global Broadcast Service (GBS), commercial narrowband, and commercial wideband SATCOM systems all work together in a robust fashion to complete the naval communication's picture. The goal of a SATCOM network is to tie the naval battlespace together in a fault-tolerant structure. As shown in Figure 7-3, each one plays an important part in communications today and in the future.

## MILSATCOM's Integrated Architecture

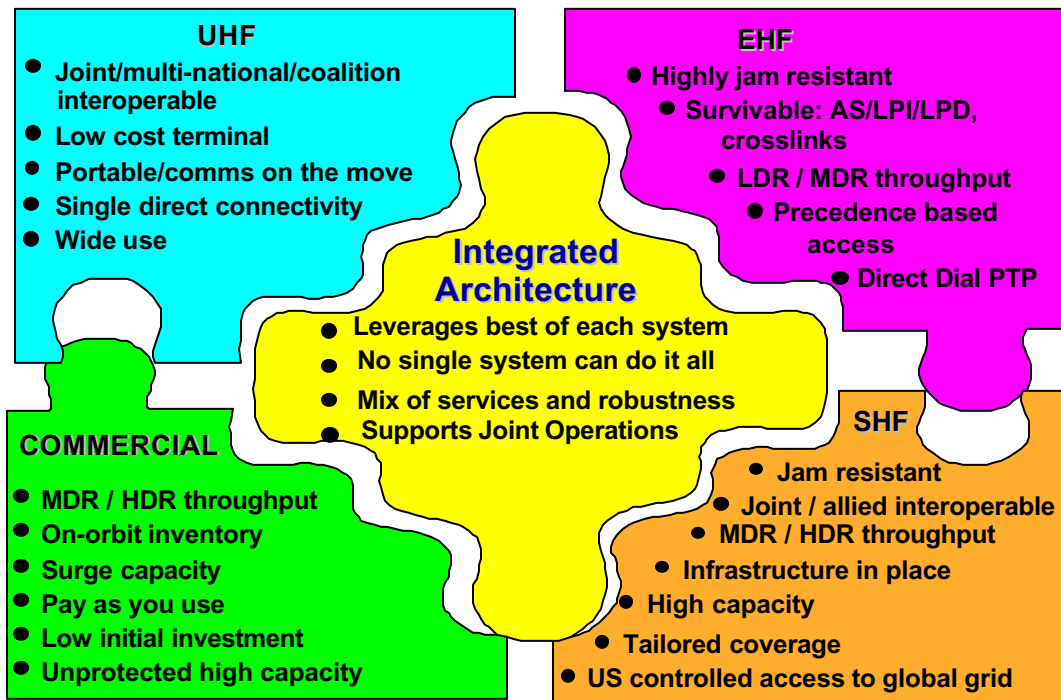


Figure 7-3. MILSATCOM's Integrated Architecture.

### Navy UHF SATCOM

The Navy UHF Satellite Communications System (UHF SATCOM) links ships, mobile units, and shore sites together using two different types of satellites as communication relays, FLTSAT and UFO. This system covers the world's surface from 70° north to 70° south latitude.

The UHF SATCOM system operates in the 225-400 Mhz band co-existing with line-of-sight (LOS) users, and is the primary system for mobile SATCOM users because the terminals are lightweight, portable, and connectivity can be established in a fairly rapid manner. The standard naval terminals include the AN/WSC-3, AN/WSC-5 (V), AN/PSC-3, and AN/PSC-5.

Typical critical circuits provided on UHF include:

- Officer in Tactical Command Information Exchange System (OTCIIXS)
- Tactical Data Information Exchange System (TADIXS A)
- Tactical Intelligence: SCI Communication Circuit (TACINTEL)
- Common User Digital Exchange System (CUDIXS)
- Fleet Broadcast

- Tactical Related Applications (TRAP)
- Submarine Satellite Information Exchange System (SSIXS)

Fleet Satellite Communications (FLTSATCOM) comprised the first constellation of UHF tactical communications satellites beginning in 1978 with FLTSAT-1. Over a period of 11 years a total of eight spacecraft were launched. In 1997, the Naval Space Command assumed on-orbit control of the FLTSAT spacecraft. Currently, only four FLTSAT spacecraft are still operational.

### Navy UHF Follow-On (UFO)

The Navy has procured a new constellation of satellites to replace the aging FLTSATs: the UHF Follow-On (UFO). The UFO features higher power transmitters designed to improve service, reliability, and dependability. The UFO satellites are mixed with the FLTSATCOM legacy system.

The UFO-4 through -9 spacecraft contain an EHF communications payload with enhanced antijam telemetry, command, broadcast, and fleet interconnectivity. There are 39 channels available up to UFO-4. The EHF payload provides an additional 11 channels, for a total of 50 channels on UFO-4 through -9. Nine UFO spacecraft are currently operational on orbit. The Navy has ordered a total of 10 satellites. Current planning includes the launch of UFO-10, and as new satellites are planned and built, they will be incorporated into the future architecture.

UFO-8 and 9 mark the first two of potentially three spacecraft configured with a GBS payload. Adapted from commercial direct-to-home television technology, GBS provides high-speed, wideband broadcast signals (receive-only) to warfighters in all branches of the military, on land, at sea, and in the air. UFO-9 is positioned over the Atlantic Ocean, and UFO-8 is located over the Pacific Ocean. When UFO-10 is launched over the Indian Ocean in 1999, the Defense Department will have near-global GBS coverage as shown in Figure 7-4.

## 1999 Constellation

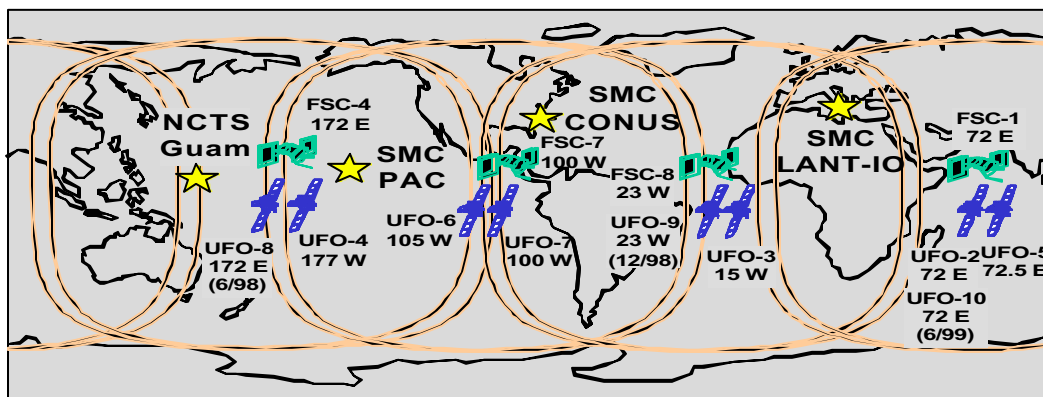


Figure 7-4. 1999 UHF MILSATCOM Constellation.



## **Demand Assigned Multiple Access Subsystem (DAMA)**

A Demand Assigned Multiple Access Subsystem (DAMA) is typically a single hop satellite transmission network which allows direct connection between any two nodes in the network among many users sharing a limited “pool” of satellite transponder space. Currently DAMA is operating in an UHF and SHF capability.

DAMA supports point-to-point or point-to-multi-point communications—any user can connect directly to any other user anywhere within the network. The result is economical and flexible bandwidth sharing with any mix of voice, FAX, video and data traffic. DAMA optimizes the use of satellite capacity by automatically allocating satellite resources to each active node upon demand.

In a DAMA system, the network allocates communications bandwidth to each call from a pool of frequency channels on a demand-assigned basis. When a caller at a remote terminal requests service, the request is made to a Network Control System (NCS) over the shared DAMA common signaling channel. The NCS functions as a “switchboard in the sky.” The NCS determines if the call is valid. The NCS then establishes the channel (including bandwidth) between the originating site and the called number. Circuits remain active only as long as needed, then are broken to free bandwidth for other users. When the call is completed, the NCS is informed by the remote terminals and the freed bandwidth is returned to the frequency pool. By using a DAMA system, a single transponder can support several thousand subscribers.

Any remote unit can be configured to perform as the Network Control System with the addition of some hardware and Network Management System (NMS) software. The hardware, together with the NMS, serves as the single focal point for system level control with the SATCOM network. The NCS can be located anywhere within the satellite footprint.

## **Navy SHF SATCOM**

The Navy SHF Satellite Communications System (SHF SATCOM) provides a high capacity and jam resistant full-duplex communications and multi-channel capability for high value naval combatants, special-purpose ships, and selected shore sites.

Although most shipboard communication is via UHF SATCOM, the very nature of SHF SATCOM (in the range of 8000 MHz) makes it an especially desirable addition to the current shipboard capability. Advantageous features of SHF SATCOM are as follows:

- Higher data rates possible than with UHF
- Jam resistant communications
- Full-duplex communications
- Secure voice communications privacy
- Real-time communications

- Narrow uplink transmission beamwidth provides low probability of intercepts
- Multiple-access capabilities allow noninterference sharing of satellite assets
- Interoperability with other services and nations

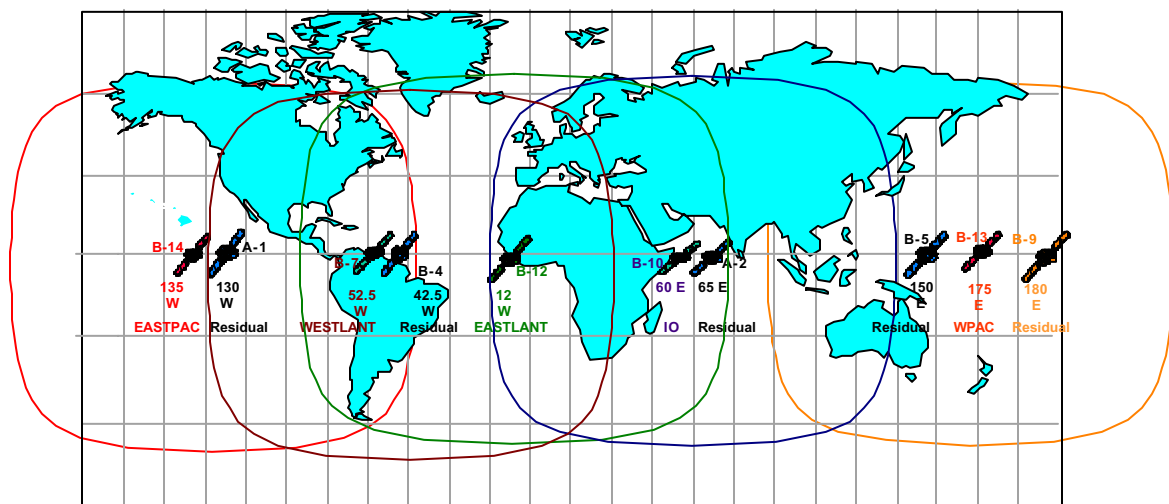
As fleet bandwidth needs continue to grow, SHF has gained importance as an operational communications capability. SHF SATCOM is now installed on most aircraft carriers, amphibious flagships, and Fleet Commander Flagships to satisfy minimum essential command and control, intelligence, and war fighting requirements. The WSC-6 terminal with both single-and dual-antenna configurations, is the primary terminal in use for shipboard SHF operations.

### Defense Satellite Communications System (DSCS)

The Defense Satellite Communications System (DSCS) is a high capacity, SHF satellite-based subsystem of the Defense Communications System (DCS). The DCS provides worldwide, jam-resistant, secure voice and high data rate communications for command and control, crises management, and intelligence data transfer service between the National Command Authority, Joint Chiefs of Staff (NCA/JCS) and the Unified Commanders-in-Chief (CINC). It also provides communications among the CINCs and their component forces, and from early warning sites to operations centers.

Currently all active and reserve satellites are DSCS III, first launched in 1982. They provide increased survivability and capability as well as greater antenna performance and flexibility over DSCS II, launched in 1971. DSCS III provides global coverage 70N to 70S with a primary constellation consisting of five satellites. Figure 7-5 displays the current constellation. Phase III is on-going with enhancements to future launches.

## DSCS III Constellation



**All active and reserve satellites are DSCS III**

Figure 7-5. DSCS III Current Constellation.

DSCS supports the Ground Mobile Force Satellite Communications (GMFSC) program, wide-band data relay for surveillance and intelligence, Navy Fleet communications, and other selected users. It provides tactical communications through the GMFSC Program. GMF (Ground Mobile Forces) terminals increase the range of and decrease the need for terrestrial relays while providing for faster system setup and disassembly. The GMF terminals also increase capacity/capability in support of tactical operations during all phases of conflict. Systems that utilize DSCS include:

- Global Command and Control System (GCCS)
- Joint Deployable Intelligence Support System (JDISS)
- Joint Worldwide Intelligence Communications System (JWICS)
- Contingency TACS Automated Planning System (CTAPS)
- Secure Telephone (STEL)
- Joint Maritime Commanders Information System (JMCIS)

NATO IV is a NATO general purpose, secure SHF MILSATCOM system. Expansion of NATO communications requirements led to the development of the current NATO IV satellites. Two NATO IV satellites make up the current constellation. The ground segment consists of fixed and mobile terminals in NATO countries. Funded entirely by NATO, the system is inter-operable with DSCS. NATO IV satellites also have two UHF channels compatible with the FLTSATCOM system.

### **Global Broadcast Service (GBS)**

The Global Broadcast Service (GBS) is derived from commercial direct broadcast technology and uses high-powered transponders to provide HDR wideband simplex broadcast signals into 1-meter or smaller antennas and sophisticated receiver suites. As aforementioned, GBS is incorporated in UFO 8, 9, and will be included eventually in UFO-10. GBS will be fully operational by mid-1999, and will be integrated into the current MILSATCOM architecture.

The GBS payload will revolutionize satellite communications by providing high-volume data and video information products to military tactical terminals. Naval Space Command has been designated the manager for GBS on UFO satellites and ensures the GBS payload is optimally configured to support the Joint user community. GBS promises to enable dominant battlefield knowledge, which will contribute to future success in military operations. Figure 7-6 explains the importance of GBS to the Navy.

## What GBS Means to Navy

- **Naval Forces are disadvantaged users**
  - Limited by antenna size or number of antennas
  - Reliant on Satellite Communications
- **Reduces over subscription to current MILSATCOM systems**
- **Supports the “Mobile” and “Disadvantaged” User**
  - Small and man-portable 22”- 36” antennas
  - Unprecedented connectivity for mobile users (land, sea, air)
- **Will greatly enhance Navy C4I capabilities**
  - Exponential increase over current SATCOM capacity
  - Smarter, faster delivery of information
  - Near-real-time receipt of imagery, data, video by the warfighter
  - Situation awareness available to lowest echelons



Figure 7-6. GBS and the Navy.

### Navy EHF SATCOM

Navy Extremely-High Frequency (EHF) Satellite Communications (SATCOM) provides enhanced anti-jam telemetry, command, broadcast, and Fleet interconnectivity communications. This payload has been on UFO flights 4-9, and will also be included in UFO-10 when launched in 1999. The Navy EHF SATCOM program is the Navy's part of the tri-service Milstar SATCOM program.

The Navy's EHF terminal, the AN/USC-38, transmits across a two GHz bandwidth at about 44 GHz. There are three versions of AN/USC-38 terminals: ship, shore, and submarine. Ship and shore terminals are capable of simultaneously transmitting/receiving four 2400 bps primary circuits and four 300 bps secondary circuits. The AN/USC-38 is also equipped with an additional four receive-only ports capable of processing up to 2400 bps each. Submarine terminals use a 6-inch dish mounted on the periscope and have two primary transmit/receive, two secondary transmit/receive, and two receive only ports. Ongoing terminal upgrades and improvements include:

- MDR: The Medium Data Rate (MDR) upgrade consists of a new modem, increase of antenna sizes, software changes, and changes to the Communications Equipment Group. It will provide 16 additional ports and increased data rates via the Milstar II satellites to be launched in 1999 through 2002.
- Interim Polar EHF: Launched in 1998, Polar EHF supplements the UHF UFO and EHF systems. All UFO/EHF satellites are in geosynchronous orbits and cannot provide coverage to Polar Regions. Polar EHF, by contrast, provides communications above 65 degrees north latitude. It supports critical submarine Low Probability of Intercept/Detection (LPI/LPD) communications, and secondarily

supports battle group operations in the Polar Regions.

- P3I: P3I provides other pre-planned product improvements including: Processor Upgrades and rehost of software; Agile Beam management to prevent communications outages when network members move; Over-the-Air-Rekey (OTAR) for automatic distribution of cryptographic keys over satellite links; In-Band Control for voice interruption notification to resolve link contention; and Navigational Digital Data Interface incorporating software that reads digital navigation data and predicts roll, pitch and heading.

In 1998, the U.S. Air Force prepared a multi-billion dollar program to replace its constellation of MILSTAR classified military communications satellites. The program is expected to be the U.S.'s most expensive venture in space to date: Advanced EHF MILSATCOM. This follow-on to MILSTAR will serve as DoD's primary means of transmitting highly protected or classified information, and like its predecessor, will be designed to operate in the aftermath of a nuclear war.

The new constellation, due for launch in 2006, is intended to be superior to MILSTAR. The Advanced EHF MILSATCOM will be able to accommodate a data throughput of about 8 Mbps, compared to the MILSTAR II medium rate payload's 1.5 Mbps.

## **COMMERCIAL SATELLITES/SATCOM ARCHITECTURE**

### **International Mobile Satellite (INMARSAT)**

The International Mobile Satellite (INMARSAT) Organization is a commercial consortium that provides satellite communications for commercial users. Headquartered in London, England, the organization operates a satellites system for global mobile communications on sea, land, and in the air. It was funded in 1979 to bring modern telecommunications to the ocean-going maritime community. With a little more than 22 percent ownership, the United States is the largest shareholder of INMARSAT. However, military use of INMARSAT is limited.

INMARSAT manages 14 satellites in a geosynchronous orbit, operating in the C and L-bands, over 4 ocean regions. The ground network consists of more than 40 earth stations. Today, INMARSAT terminals can provide voice channel surge capability and are viable alternatives to DoD owned SATCOM systems.

## Navy Commercial Narrowband INMARSAT Peaceful Use Provision

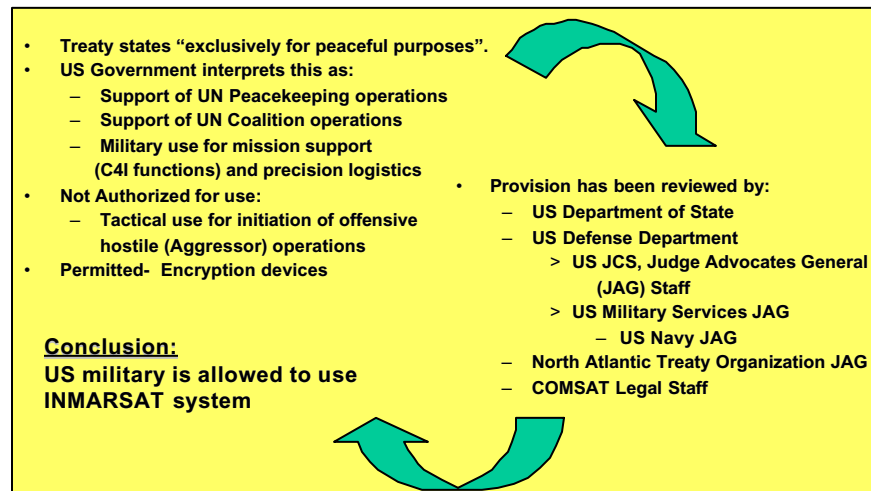


Figure 7-7. INMARSAT Use Provisions.

### International Telecommunications Satellite (INTELSAT)

International Telecommunications Satellite (INTELSAT) Organization is a non-profit cooperative formed under the leadership of the United States in 1964. The largest satellite service provider covering the globe, INTELSAT is owned and operated by 120 member nations providing service to over 180 nations and territories. The INTELSAT system consists of more than 20 satellites in geosynchronous orbit and 2700 earth stations around the world. The spacecraft are classified into four generations of satellites starting from Series-5 to Series-8 which allows for Very Small Aperture Terminal (VSAT). These satellites provide four basic types of services:

- Public switched telephone services
- Private line network (business) services
- Broadcasting (video and audio) services
- Domestic and regional services

### Challenge Athena III

The Challenge Athena was conceived to use commercial communication satellites and facilities to provide high-data-rate communications to ships. This project was driven by the need to disseminate national primary imagery for support of tactical air operations, Tomahawk mission planning, and battle damage assessment.

Current military communications satellites do not have the bandwidth expansion needed for naval ships with increasing high-data-rate requirements. The use of commercial satellite

communications parallels and augments the connectivity available through DSCS. This increased bandwidth provides National Imagery Dissemination, Telemedicine, Video Teleconferencing, NIPRNET, SIPRNET, STU-III Telephone Connectivity, and Afloat Personal Telecommunications. Challenge Athena, now in its third phase, has successfully demonstrated the ability to handle naval high-data-rate needs, providing a “non-core” communications pathway not otherwise available on DSCS. Naval requirements demand implementation of state-of-the-art technology with highly trained operators. This is achieved by fielding advanced technology demonstrations like Challenge Athena hardware, which offers high volume data communications afloat to meet fleet CINC requirements.

This increased C<sup>4</sup>I capability was first demonstrated onboard USS George Washington in 1993 and significantly enhanced operational readiness of the crew. Aircraft carriers, amphibious command ships, and Fleet Flag Ships are receiving Challenge Athena commercial wideband systems based on deployment schedules.

## **COPERNICUS**

In 1990, enhancements were made to the Navy UHF and SHF, and EHF SATCOM Systems with the integration of the Copernicus Concept for a C<sup>4</sup>I architecture and the Communication Support System (CSS). These are two evolving concepts that will significantly impact the UHF Satellite Communications System that future Naval Expeditionary Forces will employ with new capabilities in networking. Copernicus is the Navy’s initiative to make command, control communication, computers and intelligence (C<sup>4</sup>I) systems responsive to the warfighter; to field these systems quickly; to capitalize on advances in technology; and to shape our doctrine to reflect these changes. The Copernicus Architecture is an investment strategy that provides the programmatic basis for the evolution of Copernicus into the 21<sup>st</sup> century. The five pillars of the architecture are as follows:

- The Global Information Exchange System (GLOBIXS)
- The CINC Command Complex (CCC)
- The Tactical Data Information Exchange System (TADIXS)
- The Tactical Command Center (TCC)
- The Battle Cube Information Exchange System (BCIXS)

GLOBIXS supports the joint and allied tactical commanders by providing access to all required information from any location through a series of wide area Defense Communications System (DCS) networks.

The CCC serves as the primary gateway for communications and information flow from GLOBIXS to forward deployed war fighters via Tactical Data Information Exchange System (TADIXS). The CCC performs C<sup>2</sup>, correlation and fusion functions. A CINC decision-making capability, with a focus on rules of engagement and operational intent is included. Battles pace decisions are made by the tactical commanders and shooters.

The TADIXS consists of tactical networks connecting the CCCs with the Tactical Command Centers (TCCs). These tactical networks fall into four general categories: Command, Direct Targeting, Force Operations and Support. TADIXS provide enhanced digital communications links to the shooters combat systems from the Copernicus infrastructure, enabling user-pull functionality and enough computer power and bandwidth to receive and process tactical information.

The TCC disseminates information to the warfighter. The TCC can be any forward-deployed command center, ashore or afloat, mobile or fixed, and includes tactical centers for individual units. The TCC is the gateway for information flow between TADIXS and the shooter and weapons using Tactical Data Information Links (TADILs).

As Copernicus evolved, the final pillar, called the Battle Cube Information Exchange System (BCIXS), emerged. The original pillars flowed and filtered information to and from the TCC for use in the battle space. The Copernicus battle space is defined as the entire military and political infrastructure that spans the range of the pillars to the TCC. The BCIXS extends the architecture to include the battle cube, the area in which shooters and weapons reside. The battle cube is a conceptual, multi-dimensional area that includes subsurface, surface, air and space as the environment for conducting warfare.

BCIXS represents the battle cube in which tactical forces operate. BCIXS boundaries are fluid and defined by the dynamics of the battle. Shooters operating in the battle cube form the operational nodes in the BCIXS. Shooters are equipped with CI tools that allow them to receive and process information from the Copernicus architecture.

Through the five pillars, Copernicus is constructed as an interactive framework that supports the warfighter at all levels:

- The **watchstander** employs high-tech computer workstations and common interfaces.
- The **shore commanders** develop multimedia connectivity and establish rapidly configurable shore networks that link commanders to all echelons, across all Services, to all allies (whether temporary or enduring) across the full spectrum of warfare.
- The **Composite Warfare Commander (CWC)** employs a series of tactical information networks that change in number and nature to suit the CWCs doctrinal decisions and allow commanders to customize their C<sup>2</sup> needs.
- The **Commander, Joint Task Force (CJTF)** employs networks that must be flexible to permit commanders to customize their C<sup>2</sup> during joint and allied operations.

While the planning horizon extends into the 21<sup>st</sup> century, Copernicus emphasizes action and near-term results that can immediately benefit the warfighter. By designing for continuous change, Copernicus creates an evolving systems environment that focuses on the process of how we get there from here rather than defining the ultimate destination.



## **Communications Support System (CSS)**

The Communications Support System (CSS) is a communication architecture that enhances Naval Expeditionary Forces communications connectivity, flexibility, and survivability through multimedia access and media sharing. The CSS permits users to share total network capacity on a priority demand basis in accordance with the current communications plan. Automated network monitoring and management capabilities are also provided by the CSS to assist operators in the real-time allocation of communications resources. Some advantages of this approach are as follows:

- Increased communication survivability without sacrificing user throughput or communications efficiency.
- Better utilization of communication equipment through load sharing.
- The incorporation of new communications capabilities without requiring expensive changes to the user's baseband equipment or operating procedures or undue delay in implementing equipment modifications.
- The accommodation of new users on a priority basis rather than an absolute (have or have not) basis.

Perhaps best of all, these changes do not involve great expense. The required changes can be accomplished with minimal impact on funding profiles for existing and planned programs. The CSS modular approach will substantially reduce development and life cycle costs of future systems by the use of open system architecture principles.

The CSS architecture partitions the communications processing into segments. Each unique subscriber (user) has a dedicated segment to provide an interface to/from the CSS. This segment is called the Subscriber Interface Control segment, or SIC. Each radio has a segment called the Resource Access Control segment, or RAC. All software segments physically operate in one or more computers, identified as the Communications Controllers segment(s). These computers are low cost, small computers. Other CSS segments provide support functions to help the SICs and RACs transfer data between the users and the radios.

In short, the CSS demonstrates that modern technology presents the opportunity for both reduced costs and improved capabilities in Navy communications. Both the CSS and the Copernicus concepts represent the organizing constructs for naval communications in the years to come.

## **SPACE-BASED NAVIGATION SYSTEMS**

When the Soviet Union launched the first Sputnik in 1957, scientists at the Johns Hopkins University's Applied Physics Laboratory (APL) began tracking Sputnik's radio signals as it passed overhead. During their observations, they noted a Doppler shift in the signals as the spacecraft transited the ground position of their receivers.

At first the APL scientists used the Doppler shift in Sputnik's radio signals to determine the spacecraft's orbit. Later, they reversed the principles of orbit determination, and demonstrated that observers could use the signal from a satellite orbiting in a known trajectory to determine their position on the Earth. With that, space-based navigation was born.

## **Global Positioning System (GPS)**

Global Positioning Systems are space-based radio positioning systems that provide 24 hour three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth, as shown in figure 7-8. The NAVSTAR system, operated by the U.S. Department of Defense, is the first GPS system widely available to civilian users. The Russian GPS system, GLONASS, is similar in operation and may prove complimentary to the NAVSTAR system. The Global Navigation Satellite Systems (GNSS) are extended GPS systems, providing users with information of sufficient accuracy and integrity to be useable for critical navigation applications.

In the latter days of the arms race, the targeting of Intercontinental Ballistic Missiles became such a fine art that they could be expected to score a direct hit on an enemy's missile silos. Such a direct hit would destroy the silo and any missile in it. The ability to take out the adversary's missiles had a profound effect on the balance of power. In order to target and hit an enemy silo, the precise location of the launch point must be known. That is not hard to find if your missiles are on land. However, most of the U.S. nuclear arsenal was at sea on submarines. To maintain the balance of power, the U.S. had to produce a solution that allowed its submarines to surface and fix their exact position in a matter of minutes, anywhere in the world. In part, the Global Positioning System was developed to meet this need for precision location at sea.

The GPS program began in 1973, when the first test signals from space were transmitted from the Navigation Test Satellite 2. An Initial Operational Capability was declared on December 8, 1993 when 24 Block I/II/IIA satellites were operating in their assigned orbits and available for navigation use and providing Standard Positioning Service (SPS).



Figure 7-8. Global Positioning System.

GPS was developed by the Defense Department primarily to meet a military purpose. The accuracy and availability of the positional data is dependent upon the user's receive equipment. Users who have encrypted receivers can expect 16-meter accuracy from the Precise Positioning Service (PPS). Otherwise, civilian users will receive the SPS, which allows nominal accuracy to approximately 100 meters. This is due to system-induced Selective Availability - a euphemism for scrambling the GPS signal to reduce the accuracy of the data interpreted by the receiving unit. Such signal degradation yields results accurate enough to find a street address or one's favorite fishing hole, but prevents the operator from accurately flying a cruise missile into a sensitive U.S. facility. National Command Authority approval is required to change Selective Availability.

Most GPS receivers also have a built-in mapping feature that displays their positions relative to waypoints. Waypoints are intermediate locations that the operator pre-programs into the GPS. Receivers can then plot a trail that shows the path traveled to the current location. Advanced models have built-in street or waterway maps, plus serial ports for computer connections.

How GPS works in five logical steps:

1. The basis of GPS is "triangulation" from satellites.
2. To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
3. To measure travel time, GPS needs very accurate timing, which is achieved with clever use of signal characteristics.
4. Along with distance, the satellites must be precisely located in space. High orbits and careful monitoring are critically important.
5. Corrections must be made for any delays the signal experiences as it travels through the atmosphere.

The 24 satellites have staggered orbits designed to enable a GPS receiver to see four satellites from any location on earth 95 percent of the time. Seeing four satellites simultaneously is important. Each satellite broadcasts a repeating message, which indicates the position and orbital parameters of itself and the other satellites. GPS receivers maintain an "almanac" of this data for all satellites and they update these almanacs as new data comes in, usually on an hourly basis. Data includes a bill of health for the satellites, and the precise atomic time. The information is encrypted into a signal with strict timing characteristics.

GPS Triangulation - Suppose you measure your distance from a satellite and find it to be 11,000 miles. Knowing that you are 11,000 miles from a particular satellite narrows down all the possible locations you could be in the whole universe to the surface of a sphere that is centered on this satellite and has a radius of 11,000 miles. If you measure your distance to a second satellite and find out that it is 12,000 miles away, then that implies that you are not only on the first sphere, but also on a sphere that is 12,000 miles from the second satellite. Your position, therefore, is somewhere on the circle where these two spheres intersect. If you then make a

measurement from a third satellite and find that you are 13,000 miles from that one, the new information narrows your position down even further. By ranging from three satellites you can narrow your position to just two points in space as shown in figure 7-9.

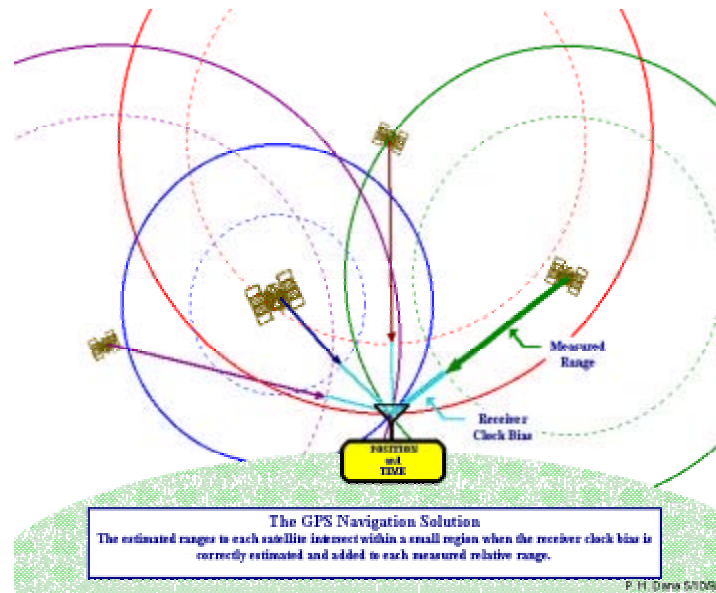


Figure 7-9. GPS Solution.

By extension, the Global Positioning System works on these principles, although it uses much more precise clocks and the speed of light. There's a hitch, though. The above example required that each person had precision-synchronized clocks. If each GPS unit had to have an atomic clock, it would be outrageously expensive. Recalling the example of three satellites, we can solve three of these four variables:

X = horizontal position

Y = vertical position

Z = altitude

t = time

With only three satellites and an imprecise clock, we have to assume altitude to be a known constant (e.g., sea level), since we can only solve for three variables using three satellites: X, Y, and time. But if we have four visible satellites, we can solve for all four variables: X (longitude), Y (latitude), Z (altitude), and t (precision time). The side effect is that not only can one's location be found precisely, but we also have precision time. Many organizations are now synchronizing their systems or network clocks to GPS signals, since it is a cheap and highly accurate chronological source.

However, there are some important caveats. The satellites must be spaced well apart. If they are too close together, the timing difference between their signals is not enough to calculate the unknown location precisely. In GPS parlance, this is "geometric dilution of precision," shown

in figure 7-10. There are usually more satellites available than a receiver needs to fix a position, so the receiver picks a few and ignores the rest. If the receiver picks satellites that are close together in the sky, the intersecting spheres that define a position will cross at very shallow angles. That increases the error margin around a position. Good receivers determine which satellites will give the lowest geometric dilution of precision.

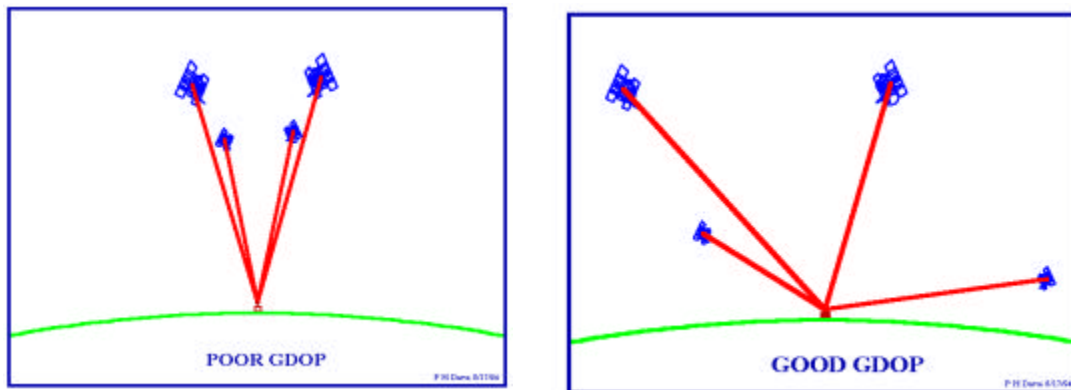


Figure 7-10. Demonstration of Good and Poor Geometric Dilution of Precision (GDOP).

Also, there must be a clear path between you and the satellites. Nothing can be blocking the satellite's signals, nor can there be a large reflective object causing unwanted echoes, "multipath" signals. GPS signals work in the microwave band. They can pass through glass, but are absorbed by water molecules, as found in wood and heavy foliage; and reflect off concrete, steel, and rock. This means that GPS units have trouble operating in rain forests, urban jungles, deep canyons, inside automobiles and boats, and in heavy snowfall. These environmental obstacles degrade positional accuracy. The three segments of the GPS are the Space, Control and User segments.

### Space Segment

The Space Segment of the system consists of GPS space vehicles that send radio signals from space. The nominal GPS Operational Constellation consists of 27 satellites, 24 operational and 3 spares, that orbit the earth in 12 hours. The orbit altitude of 10,900 nautical miles (12,500 statute miles) is such that the satellites repeat the same track and configuration over any point approximately each 24 hours. This constellation provides the user with between five and eight satellite vehicles (SVs) visible from any point on the earth. Satellites are phased to provide for loss of several satellites with minimal impact on users. Known as 'graceful degradation,' this concept implies only a partial loss of navigation capability if an SV is lost.

### Control Segment

The Control Segment consists of a system of tracking stations (figure 7-11) located around the world, operated by the US Air Force Space Command's 50<sup>th</sup> Space Wing. The Master Control Station is located at Schriever Air Force Base, (formerly Falcon AFB), near Colorado Springs, CO. An unmanned Master Control Station backup is located at Gaithersburg, MD. There are four Mission Ground Stations that monitor the satellites located at Hawaii, Ascension Island, Diego Garcia, and Kwajalein.



Figure 7-11. GPS Network.

These monitor stations measure navigation data from the satellite vehicles which is then incorporated into orbital models for each satellite. The process of grooming the health and status of each satellite is transparent to the user. The constellation operations that occur at the Master Control Station are:

- Navigation signal accuracy
- Satellite contacts/ health
- Control segment maintenance
- Contingency operations

### User Segment

The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and time. Navigation in three dimensions is the primary function of GPS. Navigation receivers are made for aircraft, ships, ground vehicles, and for personal navigation by individuals. Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning data for remote receivers. Surveying, geodetic control, and plate tectonic studies are examples. Time and frequency dissemination, based on the precise clocks on board the SVs and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects have used GPS signals to measure atmospheric parameters.

### Precise Positioning Service (PPS) and Standard Positioning Service (SPS)

Authorized users with cryptographic equipment and keys and specially equipped receivers use the Precise Positioning System. U. S. and its military allies, certain U. S. Government agencies, and selected civil users specifically approved by the U. S. Government,

are authorized to use the PPS.

Civil users worldwide use the SPS without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the DoD by the use of Selective Availability.

## **Threats to GPS**

Despite encryption, the Anti-Spoofing mode of operation, and the use of pseudo-random code signals, there exists the threat of jamming to GPS receivers. This threat extends to the associated navigation data links for Precision Guided Munitions (PGM). During Operation Desert Storm, 25% of Navy A-6 precision strike missions incurred unintentional interference problems, effectively canceling final aim point refinement. The following list presents Precision Strike Weapons (PSW) which employ GPS or data links for weapons guidance:

- Tomahawk BLK III
- Tomahawk BLK IV
- JDAM
- JSOW
- AGM-130
- GBU-15
- ATACMS
- SLAM Ver 2.42

The GPS jamming threat to GPS-guided PSWs is now widely recognized and acknowledged. Unless GPS precision strike weapons systems and their data links are equipped with significant jam resistance capability, each weapons type could be defeated by an opponent employing unsophisticated jamming techniques.

## **Accuracy**

GPS accuracy is primarily dependent upon the constellation geometry in relation to the receiver. This geometry can be modeled and used to predict periods of greater or lesser GPS accuracy. The System Effectiveness Module is a mission-planning tool designed to fully utilize the capabilities of GPS. It provides operational users the opportunity to best determine predicted GPS accuracy for an input position and time. The latest software package is available to all DoD users upon request, can be loaded onto PC-compatible computer terminal with a modem, and is menu driven and user friendly. Used primarily by the Army and the Navy, the package is also supported via daily almanac updates to better refine operational planning solutions. Contact information is:

Army Space Command / MOSC-00-D  
11670 North Newport Road  
Colorado Springs, CO 80916  
Vox: 719-554-8743/DSN 692-8743  
BBS: 719-554-8796/DSN 692-8796

or 2d Space Operation Squadron / DOA  
300 O'Malley Avenue, Box 41  
Schriever AFB, CO 80912-4035  
Vox: 719-567-6378/DSN 560-6378  
BBS: 719-567-6379/DSN560-6379

## **GPS Augmentations**

In order to obtain greater accuracy from the GPS, a second source is used to improve upon GPS-supplied data. The augmented systems are:

- Differential GPS (DGPS)
- Wide Area Augmentation System (WAAS)
- Wide Area GPS Enhancement (WAGE)
- Exploitation of DGPS for Guidance Enhancement (EDGE)
- GPS Aiding

### **Differential GPS (DGPS)**

Differential GPS (DGPS) unit receivers use GPS in combination with an FM radio receiver to overcome the errors induced by Selective Availability. The result is a receiver unit that can provide three to ten meter accuracy. The U.S. Coast Guard broadcasts DGPS signals for free along both coastlines of the United States. For a small subscription cost, users can receive DGPS signals at inland locations from various broadcast companies. The inland coast limitation will likely go away because the Federal Aviation Administration wants to use GPS for all aircraft. It plans to begin wide-scale broadcasting of free DGPS signals around the year 2000. DGPS receivers currently go for about \$500, but once the FAA plan goes into action, GPS units will probably start to have built-in DGPS receivers.

### **Wide Area Augmentation System (WAAS)**

- Expands the DGPS concept by providing GPS corrections to a wide area
- Architecture includes:
  - 24 Wide Area Reference Stations
  - 3 Geostationary COMSATS
  - Specially equipped GPS receivers



- System design by the Federal Aviation Administration
- Accuracy to 3-5 meters

### **Wide Area GPS Enhancement (WAGE)**

WAGE is very similar to DGPS, except WAGE supports a wider area by using satellite relay to distribute the corrective information over the horizon. This allows the user to utilize corrected GPS data, which is better than PPS and SPS. It should be noted that errors induced by local atmospheric conditions that DGPS corrects are not corrected by this system.

### **Exploitation of DGPS for Guidance Enhancement (EDGE)**

EDGE focuses on inserting DGPS accuracy into precision weapons. By defining the data links that will be utilized during all phases of weapon employment, EDGE ensures the corrective bias effectively reaches the Precision Guided Munition. The precision criteria for EDGE is 0.4 meters and has been achieved.

### **Nuclear Detonation Detection System**

The secondary payload onboard GPS satellites includes a variety of sensors used to detect atmospheric and space nuclear detonation in near real-time. Nuclear Detonation Detection System sensors ride as packages onboard other satellites in addition to the GPS. The 24 satellites in the constellation ensure detection of any nuclear event worldwide. The system senses nuclear detonations and passes the information to the Air Force Technical Applications Center (AFTAC) downlink locations at:

- Buckley Air Force Base (Denver, CO)
- Schriever Air Force Base (Colorado Springs, CO)

## **SPACE REMOTE SENSING**

Remote sensing is defined as the technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the objects of investigation. This information allows us to make decisions, predictions, and to model environments and situations quickly and efficiently without ever having to visit the area to be studied.

Remote sensing allows us to 'see' things we normally could not by using the entire electromagnetic spectrum as a method of detecting objects. Images are recorded in varying portions of the electromagnetic (EM) or "light" spectrum. In different portions of the EM spectrum, pictures of objects do not always appear to be their normal/visible color. In the infrared portion of the spectrum, the colors appear shifted so that green plants appear red, and a red sweater appears yellow. Parts of the visible spectrum are broken into different regions. At the highest energy level are the gamma rays and x-rays. The middle energy levels are the ultraviolet, the visible, and the infrared. Microwaves and radio waves are at the low end of the

spectrum. Remote sensing and analysis permits us to see a multitude of surface features, as they would appear on a thematic map in their appropriate spatial and contextual relationships. It is the practical, orderly, and cost-effective way of maintaining and updating information about the world around us.

Today, many countries have many satellites that orbit the earth. Data is recorded in *pixels*. The word pixel was formed as a word by combining *picture* and *element*. The pixels are then put together in a rectangular array to form a picture. So, using a satellite that has a resolution of 30 square feet within each pixel, the human eye can recognize on the picture generated by remote sensing data objects that are longer and wider than 30 feet. The military is currently working with resolutions that are 3 feet square or less. This would allow you to recognize not only a car on the ground, but also its license plate from data gathered by an orbiting satellite.

Remote sensing began in the 1840s as balloonists took pictures of the ground using the newly invented photo-camera. Aerial photography became a valuable reconnaissance tool during the First World War and came fully into its own during WWII.

After WWII, the entry of remote sensors into space began with automated photo-camera systems launched from White Sand Missile Range onboard captured German V-2 rockets. With the advent of Sputnik in 1957, the film cameras were placed on orbiting spacecraft. The first cosmonauts and astronauts carried cameras to document selected regions and targets of opportunity as they circumnavigated the globe. Sensors tuned to obtaining black and white TV-like images of the Earth were mounted on meteorological satellites. Other sensors on those satellites could make soundings or measurements of atmospheric properties over a varying range of heights.

Remote sensing matured in the 1970s when instruments were flown on Skylab, and the Space Shuttle. As an operational system for collecting information about the Earth on a repetitive schedule, LANDSAT was the first satellite dedicated specifically to monitoring land and ocean surfaces to map natural and cultural resources.

A radar imaging system was the main sensor on Seasat and, in the 1980s, a variety of specialized sensors were placed in orbit primarily as research or feasibility programs. The first non-military radar system was the Shuttle Imaging Radar (SIR-A) on the Space Shuttle in 1982. Other nations soon followed with remote sensors that provided similar or distinctly different capabilities. By the 1980s, LANDSAT had been privatized and a widespread commercial utilization of remote sensing had taken root in the U.S., France, Russia, Japan and other nations.

## **Electromagnetic Spectrum**

Ultraviolet, microwave, infrared, FM radio signals, and visible light are all considered radiation. The EM spectrum, as shown in figure 7-12, refers to all of the different types of radiation that exist. It arranges these types of radiation in order by their wavelengths, measured in microns, ( $\mu\text{m}$ ). Portions of the EM spectrum can pass through the atmosphere with little or no attenuation. These are known as atmospheric windows.

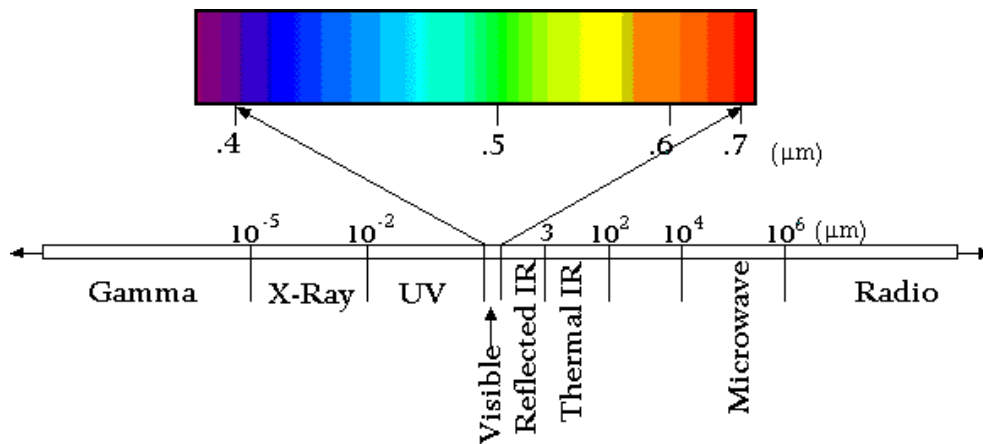


Figure 7-12. The Electromagnetic Spectrum.

To fully understand an image, an analyst must know which band (or wavelength) is used for each of the blue, green and red parts of the computer display, as demonstrated in figure 7-13. Without detailed knowledge of how each band has been changed for contrast and brightness, one cannot be sure why the colors are what they are.

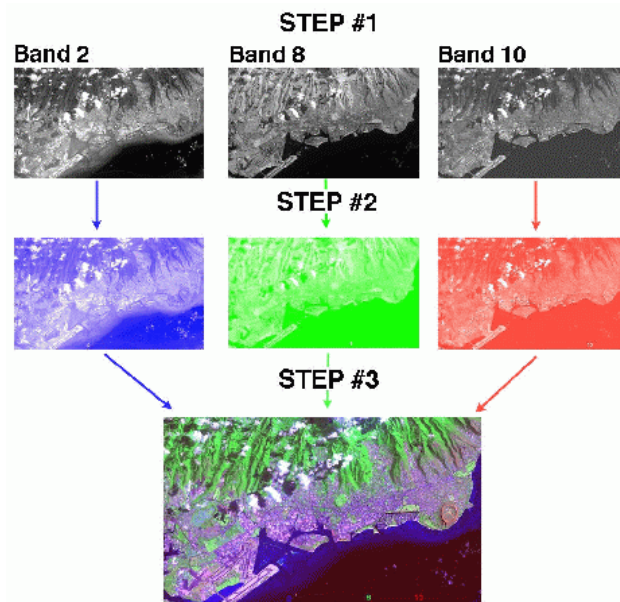


Figure 7-13. Making a Color Image.

### Radiation Hitting the Earth and its Atmosphere

On striking the land or ocean surface; or air, moisture, and clouds, the transmitted radiation, i.e., irradiance, will be partitioned into one of three primary modes of energy-interaction response. It can be absorbed, scattered, or transmitted. It may also be reflected or emitted.

## Absorption

Some radiation will be absorbed through electron or molecular reactions within the medium encountered. A portion of the incorporated energy can then be re-emitted as emittance, usually at longer wavelengths. The effect is that some of the sun's radiant energy engages in heating the target, giving rise to a thermal response. (See Emission below) Three atmospheric gasses cause absorption:

- Ozone - absorbs UV; upper atmosphere
- Carbon Dioxide - absorbs energy in the 13 - 17.5 mm region; lower atmosphere
- Water Vapor - mostly important in humid areas, very effective at absorbing in portions of the spectrum between 5.5 and 7 mm and above 27 mm; lower atmosphere.

## Scattering

Scattering is the redirection of EM energy by particles suspended in the atmosphere, or by large molecules of atmospheric gasses. There are three main types of scattering, Rayleigh, Mie, and Non-Selective.

**Rayleigh** - Upper atmosphere scattering, sometimes called clear atmosphere scattering. It is wavelength dependent and increases as the wavelength becomes shorter. Rayleigh scattering occurs when the atmospheric particles have a diameter smaller than the incident wavelength. It is dominant at elevations of 9 to 10 km above the surface. Blue light is scattered about four times as much as red light, and UV light about 16 times as red light. Rayleigh scattering is why the sky is blue. The atmospheric particles are about the size of the blue wavelength, causing a large amount of Rayleigh scattering to occur in that portion of the EM spectrum in the upper atmosphere.

**Mie** - Lower atmosphere scattering (0-5km). Caused by dust, pollen, smoke and water droplets. Particles have a diameter roughly equal to the incident wavelength. The effects are wavelength dependent and affect EM radiation mostly in the visible portion. Mie scattering is responsible for the white color of clouds in the atmosphere.

**Non-Selective** - Lower atmosphere. Particles much larger than incident radiation and scattering are not wavelength dependent. It is the primary cause of haze. Some general effects of scattering include:

- Causes skylight, which allows us to see in shadows.
- Forces image to record the brightness of the atmosphere in addition to the target.
- Directs reflected light away from the sensor aperture.
- Directs light normally outside the sensor's field of view toward the sensor's aperture decreasing the spatial detail and causing fuzzy images.

- Tends to make dark objects lighter and light objects darker, thus reducing contrast

## **Transmission**

Transmission is the movement of energy through a surface or an object, such as sunlight passing through the Earth's atmosphere, or light passing through glass. Transmission is wavelength dependent. Transmittance is measured as the ratio of transmitted radiation to the incident radiation. Plant leaves can transmit significant amounts of infrared radiation, but cannot transmit visible light as strongly.

## **Reflection**

The target surface may reflect selected portions of the EM energy striking it. The green portion of sunlight striking healthy vegetation is nearly 100% reflected, which gives vegetation its characteristic green color. Spectral reflection produces a 'bright spot' on the surface. In diffuse reflection, the incident radiation is widely scattered in all directions. Most remote sensing systems are designed to monitor reflected radiation.

## **Emission**

Emission is tied directly to absorption. Electromagnetic energy that is first absorbed by an object may be re-emitted. For example, a rock absorbs sunlight during daylight hours and then re-radiates heat energy as infrared radiation as the rock cools. Objects typically re-radiate energy at a lower wavelength than the incident energy.

## **Radar Remote Sensing**

Radar is an instrument that is called an "active sensor", because it transmits a signal that is then reflected off of a surface before being measured. In contrast, visible and infrared sensors are called "passive sensors" because they measure only the amount of sunlight reflected off of a surface. Radar measurements for the Earth are usually collected at a wavelength between 3 cm and 68 cm.

Using a radar system to study the Earth (or another planet) has several advantages over passive sensors. Because of the wavelength of the signals, radar can "see" through clouds, and, as it is an active system, it can operate day or night. It is therefore possible to image the surface whatever the weather conditions are at any time of day.

There are disadvantages, such as the non-unique spectral properties of the returned radar signal. Unlike infrared data that help us to identify different minerals on the ground, radar only shows the difference in the topography and moisture content of the ground. Radar and infrared sensors are therefore very complimentary instruments, and are often both used to study the same landscape.

Unlike instruments that look straight down, such as those found on LANDSAT, SPOT and most aircraft, radar data are collected looking off to the side of the spacecraft. Radar measures the time that it takes for the signal to go from the spacecraft to the ground and back. This is necessary to avoid the confusion of signals coming back at the same time from the left and

right sides of the spacecraft ground track. Figure 7-14 illustrates some of the common terms used to describe the geometry of a radar image. Most important is the "incidence angle", which is the angle at which the radar beam hits the surface. Also note that the "radar swath" can be of different widths depending on the radar used. Typically, this value is between 25 - 100 km, with a spatial resolution (the size of an image pixel) of about 25 meters.

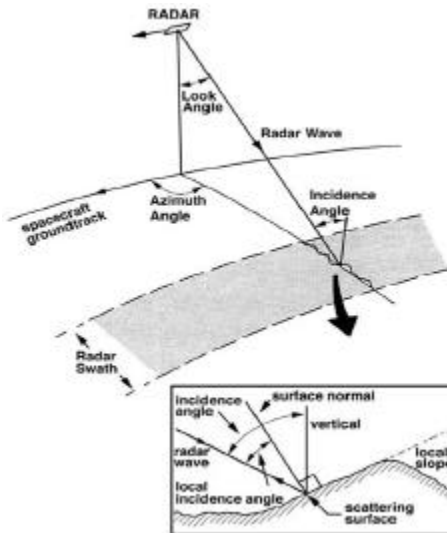


Figure 7-14. Incidence Angle.

## LANDSAT

LANDSAT is the US government's civilian remote sensing satellite system, providing multispectral imaging with a resolution of 30 meters. Its data can show deforestation, expanding deserts and other phenomena. The military uses these images for mapping and planning tactical operations.

A civil satellite system developed in the 1960s by NASA, the first LANDSAT (figure 7-15) satellite was launched in 1972. Since then, four more have been launched; the latest versions contain a multispectral (green to near infrared) scanner with an 80 meter resolution, and a thematic mapper, which can resolve objects down to 25 meters. European Space Agency (ESA) ground receiving stations can gather LANDSAT data; a company called Eurimage distributes this data, with a rush order time for images taking about five days for production and delivery. LANDSAT satellites have a circular, sun-synchronous, near-polar low earth orbit, with an altitude of 705 km; after 16 days, each satellite returns to its starting point and repeats the ground trace. Because of the importance of multispectral imagery during the Gulf War, future LANDSATs will be co-managed by the DoD and NASA; enhanced sensors capable of 5-meter stereoscopic images are expected in the next LANDSAT.

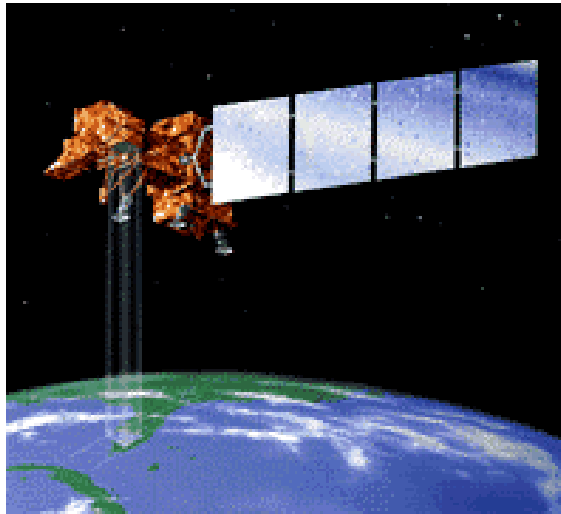


Figure 7-15. LANDSAT.

### LANDSAT: The Thematic Mapper

A more sophisticated multispectral imaging sensor, named the Thematic Mapper (TM) was added to LANDSATs 4 (1982), 5 (1984). These flew on a redesigned, more advanced platform. Although similar in operational modes to the MSS (Mobile Satellite Services, which was also part of the 4 and 5 payload, to maintain continuity), the TM consists of 7 bands that have these characteristics as shown in Table 7-1:

Band No.	Wavelength Interval ( $\mu\text{m}$ )	Spectral Response	Applications	Resolution (m)
1	0.45 - 0.52	Blue-Green	Coastal water mapping; Shallow water bathymetry; Soil/vegetation differentiation;	30
2	0.52 - 0.60	Green	Green reflectance/vegetation health	30
3	0.63 - 0.69	Red	Chlorophyll absorption for plant species differentiation	30
4	0.76 - 0.90	Near IR	Biomass surveys; Land/water boundary differentiation	30
5	1.55 - 1.75	Mid-IR	Vegetation moisture measurement	30
6	10.40 - 12.50	Thermal IR	Plant heat stress monitoring; Seawater surface temperature determination and other thermal mapping	120
7	2.08 - 2.35	Mid-IR	Hydrothermal and other thermal mapping	30

Table 7-1. LANDSAT TM.

## **DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)**

Since the mid-1960s, when the DoD initiated the Defense Meteorological Satellite Program (DMSP), low-earth-orbiting satellites have provided the military with important environmental information. The Defense Meteorological Satellite Program is a space and ground-based system used for collection and timely dissemination of global environmental data to the DoD and other governmental agencies. This environmental data consists of visible and infrared (IR) cloud cover, bodies of water, snow, fire, and pollution in the visual and infrared spectra, and other specialized meteorological, oceanographic, and solar-geophysical information required to support worldwide DoD operations.

DMSP is composed of the Space Segment; the Command, Control, and Communications Segment (C<sup>3</sup>S); and the User Segment. The principal function of the Space Segment is to continually acquire environmental data through its satellite sensors. This data is stored onboard the satellite for delayed transmission to the C<sup>3</sup>S. Subsequently, the data is relayed to strategic elements of the User Segment for processing and analysis. Realtime environmental data can also be transmitted directly from the Space Segment to tactical elements of the User Segment.

### **Space Segment**

The Space Segment consists of the DMSP spacecraft, the launch vehicle, and ground and factory support for the launch. The spacecraft is placed into a near-circular, Sun-synchronous polar orbit at a nominal altitude of 450 nautical miles. The spacecraft is 3-axis stabilized and Earth oriented. Sensing instruments are maintained in a continuous orientation toward Earth or space. The solar array rotates about the pitch axis to provide single-axis Sun orientation.

### **Command, Control, and Communications Segment (C<sup>3</sup>S)**

The C<sup>3</sup>S consists of the DMSP Multi-Purpose Satellite Operations Center (MPSOC) and the Fairchild Satellite Operations Center (FSOC), which are dedicated DMSP sites belonging to the Air Force Satellite Control Network (AFSCN). The C<sup>3</sup>S is augmented with AFSCN Remote Tracking Stations (RTSs) for launch, early orbit, and certain other orbital passes. The C<sup>3</sup>S conducts all mission planning, generates real-time and stored program commands, provides computer memory uploads to the Space Segment, and handles telemetry acquisition, processing, and postpass analyses.

Two DMSP satellites operating in low earth orbit (LEO) have continuously provided weather observation data for over 20 years. With a 1600 nautical mile-wide footprint, DMSP provides visual and high resolution infrared imagery of cloud cover, thunderstorms, sandstorms and hurricanes, and atmospheric temperature profiles. The data is used primarily by military weather forecasters and theater commanders for training and operational planning.

### **Fleet Numerical Meteorology Oceanography Center**

The Fleet Numerical Meteorology Oceanography Center (FNMOC) is one of two primary weather centers of the Naval Oceanographic Command. FNMOC receives DMSP data with a subset of the Data Reconstruction System equipment. FNMOC systems utilize DMSP



satellite data and conventional weather data to analyze and forecast atmospheric and oceanic conditions. Analyses and forecasts are used to create tactical products such as:

- Passive and active acoustic propagation conditions
- Ballistic wind and density forecasts
- High-resolution visible and infrared cloud imagery
- Atmospheric temperature and moisture profiles
- Ice edge mapping
- Precipitation measurement
- Space environment/ionospheric data

### **Tactical Terminals**

Several generations of tactical terminals, known as TACTERMs, have been used since the mid-1960s. These systems receive, process, and display DMSP data to support missions worldwide. The current systems include the Rapid Deployment Imagery Terminals, the Mark IV-B, the AN/SMQ-11, and the Mark IV terminals.

### **AN/SMQ-11 Shipboard Receiving Terminal**

The AN/SMQ-11 Shipboard Receiving Terminal, shown in figure 7-16, is a meteorological data terminal developed for naval shipboard use. This system provides dry-film, photographic quality printouts of data transmitted from DMSP satellites, TIROS-N (Advanced Television Infrared Observation Satellite), and GOES Weather Facsimile (WEFAX). The system provides the Navy with secure, high-resolution, direct readout of visual and infrared imagery. Imagery from the satellite can be used in tactical air support, antisubmarine warfare, and general weather information within 3 minutes of receipt from the spacecraft.

The first 24 AN/SMQ-11 systems employ a dual UHF planar-array antenna subsystem mounted on a single pedestal. One of the two arrays is used to receive data from DMSP satellites and the second is used to receive data from TIROS-N or GOES-WEFAX satellites, although not concurrently. System serial number 25 and all later systems employ a single UHF planar-array antenna subsystem mounted on a single pedestal. Antenna control provides stable, programmed tracking of polar-orbiting and geostationary satellites through Sea State 5.

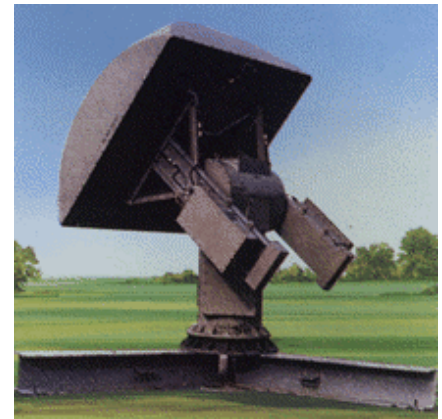


Figure 7-16. The AN/SMQ-11 Receiving Terminal.

### **DMSP SSM/I Significantly Improves Forecaster Capability**

One of the newer mission sensors on the DMSP spacecraft is the SSM/I, or the Microwave Imager. The Microwave Imager contains a passive microwave radiometer that measures the thermal energy emitted and reflected by the Earth's atmosphere using the microwave portion of the electromagnetic spectrum. Various combinations of the seven channels are used to derive precipitation rates, water content in clouds and soil, land types, temperature, and wind speeds.

### **NOAA's Geostationary and Polar-Orbiting Weather Satellites**

The National Oceanographic and Atmospheric Administration's (NOAA) operational weather satellite system is composed of two types of satellites: geostationary operational environmental satellites (GOES) for short-range warning and "now-casting" and polar orbiting environmental satellites (POES) used for longer-term forecasting. Both kinds of satellite are necessary for providing a complete global weather monitoring system. The primary customer is NOAA's National Weather Service, which uses satellite data to create forecasts for the public, television, radio, and weather advisory services. Satellite information is also shared with various Federal agencies, such as the Departments of Agriculture, Interior, Defense, and Transportation; with other countries, such as Japan, India, and Russia, and members of the European Space Agency (ESA); and with the private sector.

A new series of GOES and polar-orbiting satellites was developed for NOAA by the National Aeronautics and Space Administration. The new GOES-I through M series provides higher spatial and temporal resolution images and full-time operational soundings. The polar-orbiting meteorological satellites (beginning with NOAA-K in 1998) provides improved atmospheric temperature and moisture data in all weather situations.

## GEOSTATIONARY ENVIRONMENTAL SATELLITES (GOES)

GOES satellites (figure 7-17) provide the type of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which allows them to hover continuously over one position on the surface. Because they stay above a fixed spot on the surface, they provide a constant vigil for the atmospheric "triggers" for severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop, the GOES satellites are able to monitor storm development and track their movements.

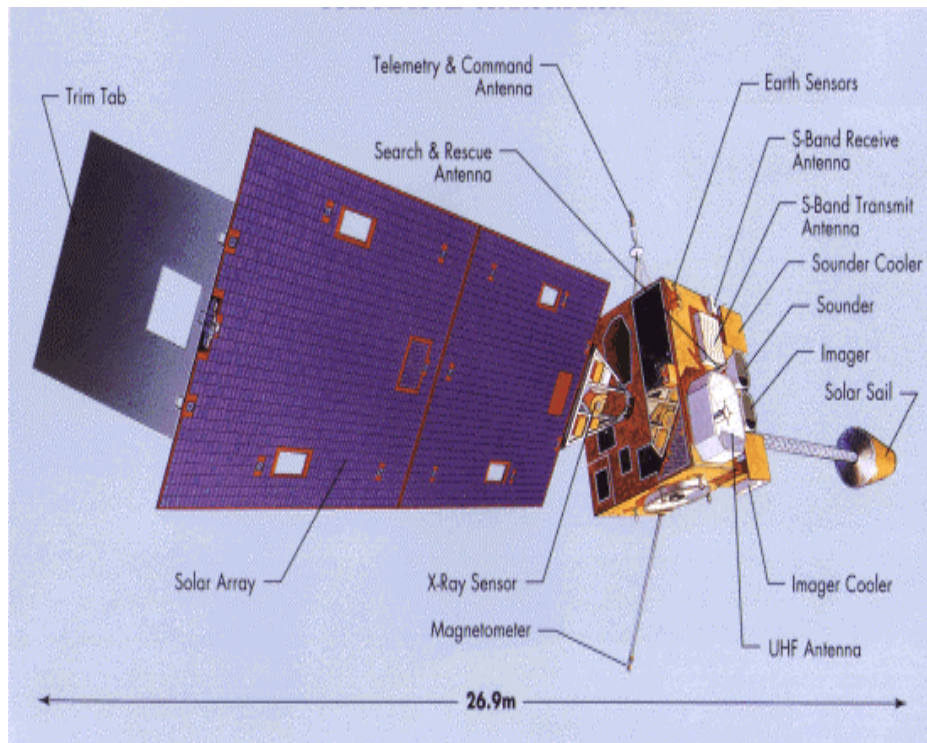


Figure 7-17. GOES.

GOES satellite imagery is also used to estimate rainfall during the thunderstorms and hurricanes for flash flood warnings. It also estimates snowfall accumulations and overall extent of snow cover. Such data help meteorologists issue winter storm warnings and spring snow melt advisories. Satellite sensors also detect ice fields and map the movements of sea and lake ice. NASA launched the first GOES for NOAA in 1975 and followed it with another in 1977. Currently, the United States is operating GOES-8 and GOES-10, launched in 1997. GOES-9 (which malfunctioned in 1998) is being stored.

## GOES-8 and GOES-10

The United States normally operates two meteorological satellites in geostationary orbit. Each satellite views almost a third of the Earth's surface: one monitors North and South America and most of the Atlantic Ocean, the other North America and the Pacific Ocean basin as seen in figure 7-18. GOES-8 is positioned at 75 W longitude and the equator, while GOES-10 is positioned at 135 W longitude and the equator. The two operate together to produce a full-face picture of the Western hemisphere, day and night. Coverage extends approximately from 20 W longitude to 165 E longitude. The figure below shows the coverage provided by each satellite.

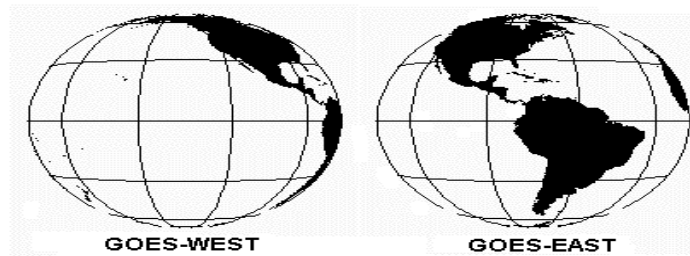


Figure 7-18. GOES positioning.

## GOES Primary Instruments

The main mission is carried out by the primary instruments, the Imager (figure 7-19) and the Sounder. The imager is a multichannel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution.

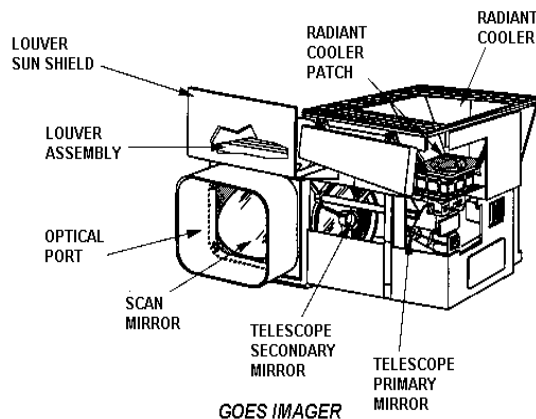


Figure 7-19. GOES Imager.

Other instruments on board the spacecraft are a Search and Rescue transponder, a data collection and relay system for ground-based data platforms, and a space environment monitor. The latter consists of a magnetometer, an X-ray sensor, a high energy proton and alpha detector, and an energetic particles sensor. All are used for monitoring the near-Earth space environment or solar "weather."

## **GOES Tactical Utilization**

Goes generates the following products for use by tactical commanders:

- Short interval, repetitive high-resolution visible and infrared cloud imagery
- Atmospheric temperature and moisture profiles
- Space environment monitoring

## **NOAA Polar Orbiting Environmental Satellites (POES)**

Complementing the geostationary satellites are two polar-orbiting satellites known as Advanced Television Infrared Observation Satellite (TIROS-N or ATN), constantly circling the Earth in an almost north-south orbit, passing close to both poles. The orbits are circular, with an altitude between 830 (morning orbit) and 870 (afternoon orbit) km, and are sun synchronous. The circular orbit permits uniform data acquisition by the satellite and efficient control of the satellite by the NOAA Command and Data Acquisition (CDA) stations located near Fairbanks, Alaska and Wallops Island, Virginia. Operating as pair, these satellites ensure that data for any region of the Earth are no more than six hours old.

Currently, NOAA is operating two polar orbiters: NOAA-14 launched in December 1994 and a new series of polar orbiters, which began with the launch of NOAA-15 in May 1998.

A suite of instruments is able to measure many parameters of the Earth's atmosphere, its surface, cloud cover, incoming solar protons, positive ions, electron-flux density, and the energy spectrum at the satellite altitude. As a part of the mission, the satellites can receive, process and retransmit data from Search and Rescue beacon transmitters, and automatic data collection platforms on land, ocean buoys, or aboard free-floating balloons. The primary instrument aboard the satellite is the Advanced Very High Resolution Radiometer, or AVHRR.

## **Advanced Very High Resolution Radiometer (AVHRR)**

The AVHRR is a radiation-detection imager used for remotely determining cloud cover and the surface temperature. This scanning radiometer uses five detectors that collect different bands of radiation wavelengths. Measuring the same view, this array of diverse wavelengths, after processing, will permit multi spectral analysis for more precisely defining hydrologic, oceanographic, and meteorological parameters. One channel monitors energy in the visible band, and another channel monitors energy in the near-infrared portion of the EM spectrum to observe vegetation, clouds, lakes, shoreline, snow, and ice. Comparison of data from these two channels can indicate the onset of ice and snow melting. The other three channels operate entirely within the infrared band to detect the heat radiation from and hence, the temperature of land, water, sea surfaces, and the clouds above them.

The polar orbiters are able to monitor the entire Earth, tracking atmospheric variables and providing atmospheric data and cloud images. They track weather conditions that eventually

affect the weather and climate of the United States. The satellites provide visible and infrared radiometer data that are used for imaging purposes, radiation measurements, and temperature profiles. The polar orbiters' ultraviolet sensors also provide ozone levels in the atmosphere and are able to detect the "ozone hole" over Antarctica during mid-September to mid-November. These satellites send more than 16,000 global measurements daily, adding valuable information for forecasting models, especially for remote ocean areas, where conventional data are lacking.

### **POES Tactical Utilization**

POES generates the following products with tactical applications:

- High-resolution visible and infrared cloud imagery
- Atmospheric temperature, moisture, and ozone profiles
- Space environment monitoring
- Sea surface temperature and eddy mapping over cloud free areas
- Search and rescue services

### **QUICK REFERENCE CHART**

<b>SPACECRAFT / SENSOR</b>	<b>APPLICATIONS / AVAILABILITY</b>
<b>AVIRIS</b> Airborne Visual Infrared Imaging Spectrometer	Mapping of minerals and vegetation. Available from NASA JPL (Jet propulsion laboratory).
<b>CASI</b> Compact Airborne Spectrographic Imager	Chlorophyll concentration, sediment distribution and vegetation studies.
<b>Challenge Athena III</b>	Provides high-data rate communications to ships through the Defense Satellite Communications System (DSCS).
<b>Copernicus</b>	Navy's communication architecture for the 21 <sup>st</sup> century.
<b>CSS</b> Communications Support System	Communications architecture that uses multi-media access and media sharing to enhance NEF communications connectivity, flexibility, and survivability.
DAEDALUS DS-1268 SCANNER DAEDALUS DS-1260 SCANNER	Used for identification and mapping of iron oxide species, rare earths, geobotanical stress and resource mapping, similar to TM.
<b>DAMA</b> Demand Assigned Multiple Access	UHF, SHF Communications subsystem that provides access to user automatically on demand.
<b>DSCS</b> Defense Satellite Communications System	SHF, high-capacity subsystem of the DCS, currently in Phase III.
<b>ERS-1</b> Environmental Research Satellite-1	Uses advanced microwave/radar techniques that will allow imaging, irrespective of cloud and sunlight conditions. Measurements include sea states, sea surface winds, ocean circulation and sea/ice levels as well as ocean and land surface applications. Launch 1991.
<b>GBS</b> Global Broadcast System	High-powered broadcast that will be fully operational in mid-1999 to provide data and video information products to military tactical terminals.
<b>GCCS</b> Global Command and Control System	A global system that will provide High data rate capability using GBS and Challenge Athena to accommodate Navy
GEOSCAN MK I SCANNER GEOSCAN MK II SCANNER	Identifying and mapping iron oxides and phyllosilicate minerals on the ground from the air. Lithologic mapping. Alteration mapping as for ATM and resource mapping. Used by CSIRO/DEG (Commonwealth scientific and industrial research organization) and Geoscan.
<b>GERIS BAND SCANNER</b>	Identification and mapping of minerals and

Global Environmental Radar Imaging System	vegetation.
<b>HCMR</b> Heat capacity Mapping Radiometer	Used to determine heat capacity of rock types and monitor soil moisture, snow cover, plant canopy temperature and thermal effluents.
<b>INMARSAT</b>	Commercial consortium providing services to commercial users, originally funded to bring SATCOM to maritime community .
<b>INTELSAT</b>	Non-Profit cooperative, largest satellite provider in the world, allows for VSATs and some military use.
<b>JTAGS</b> Joint tactical Ground station	Transportable, in-theater element of the TES, used to coordinate tactical warning.
LANDSAT MULTISPECTRAL	Vegetation, iron oxide mapping. Geographic base for co - registering geological data.
LANDSAT THEMATIC MAPPER	Vegetation, iron oxide, clay mineral concentrations, lithologic, and structural mapping. Photo-interpretation. Wide range of commercial. Government and research users.
MEIS-II SCANNER	Airborne scanner system marketed by MacDonald, Dettwiler and Associates. Uses include identification of iron oxides, rare earths and geo-botanical stress.
MONITEQ (PM1)	Chlorophyll concentration, sediment distribution and vegetation studies, MONITEQ (CANADA).
MOS-1 MESSR SCANNER	A multispectrum electronic self-scanning radiometer (MESSR). Land/water uses, discrimination of green growth and bare soil, geological.
MOS-1 MRS	A microwave scanning radiometer (MSR). Uses include water vapor measurements, weather front. Rain region, oil contaminant and snowfall measurements.
MOS-1 VTIR SCANNER	A visible and thermal infrared radiometer (VTIR). Used to detect thermal radiation form the earth's surface.
Network-Centric Warfare	Utilizes information as a weapon, composed of information, sensor and engagement grids that overlap and form "the battlecube"
NIMBUS CZCS	Designed to measure chlorophyll concentration, sediment distribution and sea surface temperature (SST).
NOAA-9/NOAA-10/NOAA-11	Fire mapping, flood monitoring, drought and vegetation assessment (NDVI), sea surface temperature, weather forecasting, geological. Available form NOAA/NESDIS, ACRES and STATE NOAA receiving centers.



NS001 SCANNER	NASA eight-band aircraft scanner. Similar band range to thematic mapper, TM, data with an extra band in near infrared range. Applications, including natural resource monitoring, similar to thematic mapper.
<b>OCEAN COLOUR SCANNER</b> (OCS - CSIRO)	Also flown on the CSIRO VHCAT aircraft and is a rotating mirror scanner designed mainly for ocean color work, chlorophyll absorption.
<b>SAR</b> Synthetic Aperture Radar	Structural mapping in heavily vegetated areas, environmental monitoring. Available at selected sites from AUSLIG (Australian surveying and land info group).
SCANNER (MSS)	Other geophysical/geological data. Lithologic and structural mapping. Map revision at 1:1000,000 1:250,000. Wide range of commercial, government and research users.
SPOT	French satellite sensor allows vertical and selectable viewing, providing opportunity for acquisition of stereo pairs and ability to obtain daily coverage of selected. Uses: agriculture, cartography/map revision, environmental monitoring, urban planning.
TIMS SCANNER	Uses include emissivity mapping of silicate and carbonate minerals, quartz content discrimination, lithological mapping.
<b>UFO</b> UHF Follow-On	UHF follow-on, most current launch: UFO-9, contains GBS and EHF payloads
UHF, SHF, EHF	The three MILSATCOM Systems capabilities that support DoD C <sup>4</sup> I



# **CHAPTER 8**

## **FOREIGN SPACE PROGRAMS**

### **INTRODUCTION**

The rapid growth and development of world economies continues to be an impetus for space programs worldwide. The need for information, communications, and military capabilities all play a role in the demand for new technological and scientific developments. Entering the 21<sup>st</sup> century, space programs will continue to challenge and inspire man.

While the United States can still be considered the leading nation in space, several other countries are not too far behind. China, Japan, Europe, and Russia all possess cutting-edge technology and more than capable manpower.

More importantly than the existing competition between these space programs is the cooperative efforts these countries (and others) engage in. Now more than ever, the sharing of knowledge and technology transfer has become paramount. In addition to individual space programs, many countries belong to consortia. Cooperative efforts abound, assisting man in their mission to conquer and master space.

### **CHINA - PEOPLE'S REPUBLIC OF CHINA (PRC)**

The Chinese Space Program is one of the least known national programs of space exploration. Yet astronomy, rocketry, and space exploration have a long tradition in China. The rocket was invented there and the Chinese Space Program was formally established in 1956, before the first Sputnik even orbited the Earth.

The Chinese Communist leadership recruited scientists expelled from the United States to build a program to match those of the Americans and the Russians. Political turmoil then interrupted the development of the program - the great leap forward, the Cultural Revolution, political reorganization and diplomatic isolation. Not until 1970 did the People's Republic of China (PRC) launch its first space satellite.

China launched its first weather satellites to 500-mile high polar orbits in 1988 and 1990. They were called Feng Yun, or Wind and Cloud, and were similar to U.S. National Oceanographic and Atmospheric Administration (NOAA) weather satellites. The satellites had infrared and visible-light sensors and transmitted data on clouds, ocean surface temperatures, marine water color, Earth's surface, vegetation growth and ice and snow cover to ground stations. China first launched a weather satellite to stationary orbit in 1988.

The PRC used remote-sensing technology at the end of the 1980's to monitor floods in the lower and middle reaches of the Yangtze and Yellow rivers. The nation also used satellites to map its forest resources and see society's impact on the ecology of northwestern, north-central and northeastern regions of China. Among remote-sensing devices in its satellites are imaging spectrometers, infrared multispectral scanners, microwave radiometers and synthetic-aperture side-looking radar.

China has since developed a space program comprising over 50 scientific probes, recoverable cabins, weather and communications satellites. China has built a family of launchers in the Long March series, constructed three launch sites and developed a formidable infrastructure of space facilities. Chinese launchers have made a modest impact on the world commercial launcher market.

## Chinese Launchers

Principal responsibility for the design and production of Chang Zheng (Long March), or CZ family launch vehicles (the main launch vehicle in use), lies with the China Academy of Launch Vehicle Technology (CALT) and the Shanghai Academy of Spaceflight Technology (SAST), both of which belong to the China Aerospace Corporation (CASC).

As of June 1998, China had conducted 60 space launches, of which 49 were completely successful, with another 7 failing to reach orbit and 4 suffering post-launch failures. This failure rate is substantially higher than its primary Eurasian competitors and Japan. Despite a relatively low domestic launch demand - typically 2-3 satellites annually - the PRC has developed and is expanding, in part for commercial reasons, a surprisingly diverse inventory of launch vehicles to support both LEO (low earth orbit) and GEO (geosynchronous earth orbit) missions. Figure 8-1 displays the Long March Family.

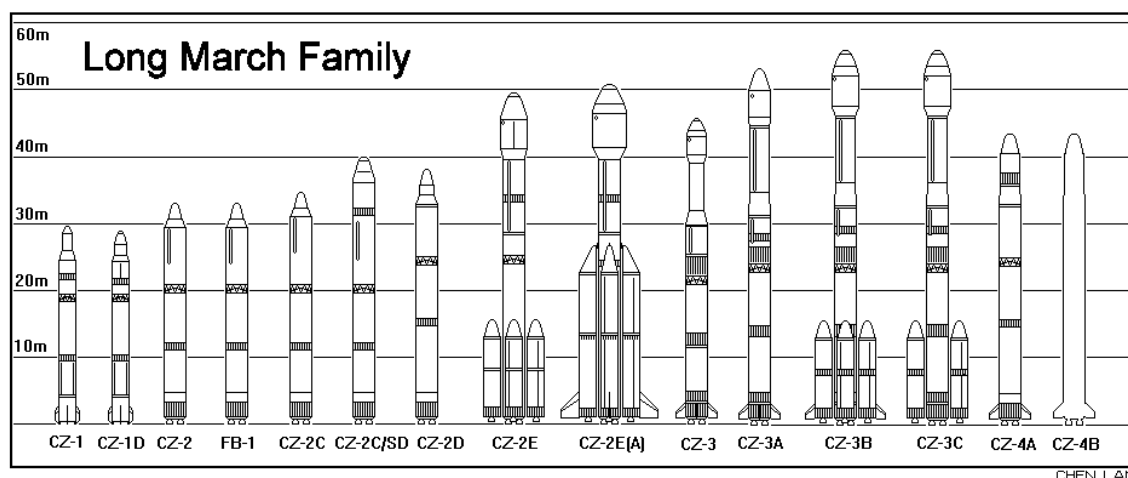


Figure 8-1. Long March Family.

## Chinese Satellite Communications

China's satellite communications began in 1972 with the visit of former US President Nixon. While the event was broadcast to a world audience via INTELSAT's (international telecommunication satellite organization) Indian and Pacific Ocean satellites, China's exposure to satellite communications and geopolitical circumstances prompted the country to develop its own space programs, including communications satellites and missiles that later evolved to launch vehicles.

With over 25 years of development, China's satellite communications market has grown to a sizable communications sector with capability of designing and manufacturing satellites, rockets, and a network of international gateways, domestic network (Domsat), and VSATs (very small aperture terminals).

For over a decade (between 1972-84), China relied essentially on INTELSAT and InterSputnik satellites for its domestic and international communications. Television broadcast was the primary service with some voice traffic for domestic communications; voice and low-speed data communications were the main services for international communications.

China began its own R&D on communications satellites in the late 1970s. In early 1984, a Chinese Long March rocket launched the first experimental communications satellite, code named Dong Fang Hong (DFH-1) as shown in Figure 8-2. Soon after, a second experimental satellite (DFH-1A) was launched into a geostationary orbit. These early experiments were for demonstration only with very limited capacity and power, and had a short operation life (four years).

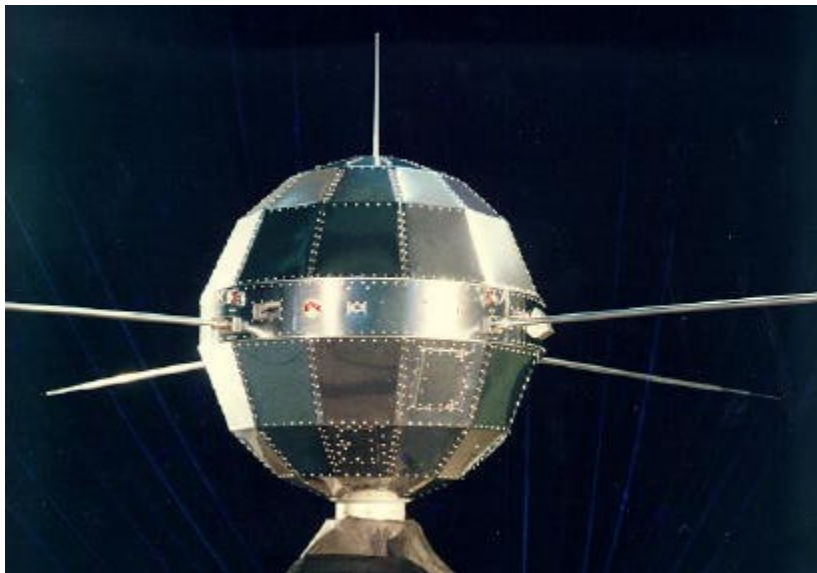


Figure 8-2. DFH-1.

At this time China was still closed to western technology and information exchange, and relied solely on its own design, manufacturing and testing capabilities. Steady progress followed initial success. In 1986, China successfully launched DFH-2, also an experimental satellite. DFH-2 followed the same design and configuration as DFH-1 and 1A, except for a regional beam antenna and a higher effective isotropic radiated power (EIRP). DFH-2 was capable of covering the entire country and used for transmitting TV programs to remote areas.

In 1988, China launched three more DFH communications satellites, named DFH-2A-1, 2A-2, 2A-3 (later renamed ChinaSat-1, ChinaSat-2 and ChinaSat-3). DFH-2As were a modified version of DFH-2, and the first equipped with full communications functionality. All DFH-2As have since been replaced by a new generation of DFH-3s (Figure 8-3), each with 24 C-band transponders.



Figure 8-3. DFH-3.

To a large extent, the significance of DFH satellites is not their capacity; in fact, DFHs did not solve much of the communications problems due to their limited transmission capacity and largely under-served demand. On the other hand, the early success of design, manufacturing and launch of DFH satellites demonstrated that China took space programs seriously, and was determined to join the international satellite communications market through its own resources and development.

As China began a large-scale construction of its telecommunications infrastructure, it became evident that the policy on self-reliance would be time-consuming and costly. China initiated a new telecommunications policy in the early 1990s, in which satellites were designated as one of the primary transmission media for the country's backbone and access for voice communications. Clearly, satellites were selected for their advantages in large coverage, short deployment time, and cost-effectiveness. This policy contributed

significantly to the rapid growth of the satellite communications market in this period, which also includes Very Small Aperture Terminal (VSAT) networks.

In the meantime, China began to seek alternative sources for space segments. The market received a boost from Asia Satellite Telecommunications (AsiaSat) with its first communications satellite, AsiaSat-1.

## **ASIASAT**

AsiaSat-1 (Figure 8-4) was launched in April 1990 by a Long March rocket and positioned at 105.5 degrees East, which is considered to be optimal for covering all of China and Southeast Asia. AsiaSat-1 has 24 C-band transponders with a center EIRP (effective isotropic radiated power) of 37dBW (equally divided to northern and southern beams) and its successful launch greatly relieved space segment supply.



Figure 8-4. AsiaSat-1.

AsiaSat-1 turned out to be the precursor of a series of launches during this period that significantly increased the supply of space segments. In July 1992, China Telecommunications Broadcasting Satellite (ChinaSat), a public satellite operator under the Ministry of Radio, Film and Television (MPT), purchased an in-orbit satellite from former GTE's Spacenet-1, and drifted it to 115.5 degrees East.

## **APStar**

Another boost during this period came from APStar-1. Owned and operated by APT Satellite in Hong Kong, APT Satellite is a consortium of four regional companies in which China holds a major interest (three of four founding members are Chinese state run entities). APStar-1 was launched successfully in July 1994 by a Long March rocket and positioned at 131 degrees East, and has a capacity of 28 C-band transponders. Like AsiaSat-1, APStar-1 had the intention of targeting China as its primary service territory, along with other Southeast Asian countries. As a result of successful satellite purchase and

launches, China was able to extend total availability of space segments from about ten transponders in the early 1990s to more than 40 by 1995.

China's satellite communications market entered an adjustment phase in 1996 with a number of indications. Development during this period was heavily affected by the following factors:

- Very Small Aperture Terminal (VSAT) technology and its roles in total communications landscape;
- Rapid deployment of terrestrial systems; and
- Setbacks from a series of launch failures that delayed Ku-band supply and deployment of Ku-band based VSAT networks.

Supply of C-band transponders has changed from scarcity to an adequate scale. Despite a number of launch failures, space segments acquired in the early and mid-1990s continued to provide reliable services, especially for TV distribution, voice communications, and data relay.

There are three public satellite operators in China: ChinaSat, China Orient Telecommunications Satellite, and Sino Satellite Communications.

The military, which was a satellite operator for DFHs, has merged into the commercial service market since 1994. All three operators provide public satellite communications services as the result of deregulation and competition. At present, only ChinaSat provides technical support and is authorized for international service.

## **ChinaSat**

China Telecommunications Broadcast Satellite (ChinaSat) was established in 1983. Its initial objective was to provide a satellite-based TV broadcast network to China's remote areas. Indeed, ChinaSat's early activity was essentially TV-related with little communications service, and was originally set up as an independent forum dominated by the Ministry of Radio, Film and Television (MPT). The role of ChinaSat began to change in 1986 when the first phase of Domsat went in to operation. In addition to TV transmission, the domestic satellite network was a national backbone network that carried voice traffic to remote areas which terrestrial facilities did not cover. The expansion of satellite capacity has brought increasing participation from ChinaSat. As the result of industry reform that separated service from regulation, ChinaSat has become a subsidiary of China Telecom, the largest national carrier for all communications services.

The role of ChinaSat has also changed significantly. Prior to 1993, ChinaSat was essentially an advisor group without operations because it did not own any space segments; all space programs were strictly classified and all DFH satellites were operated by the military. The situation began to change in 1993 when China purchased Spacenet-1. Since



the military was not allowed to engage in commercial activity, THE Chinese the Ministry of Radio, Film and Television (MPT) made the purchase, which subsequently became China's first civilian satellite. Thus, ChinaSat became China's first commercial satellite operator. Since a failed launch in 1994, ChinaSat has replaced the military and become the official operator of DFHs for commercial applications.

ChinaSat, with its parent company China Telecom, is the largest investor in China's public satellite communication service market and operates one of the world's largest domestic satellite networks. In addition, ChinaSat houses the highest concentration of uplink equipment in China. In 1996, a national emergency satellite network went into operation; when all phases are completed, the network will cover more than 60 percent of provinces. ChinaSat is operating the redundant VSAT network. In addition, ChinaSat provides international settlement service to more than 70 international carriers (direct) through its gateway stations in Beijing, Shanghai and Guangzhou.

### **China Orient Telecommunications Satellite**

China Orient was formed in April 1995 as a limited liability company. Officially, China Orient is loosely attached to the Ministry of Radio, Film and Television (MPT) for its business activities and is subject to MPT supervision. In actuality, China Orient has attained a high degree of autonomy in satellite procurement, service provisioning, network management and investment. This is another indication of separation of administration from business operations, and the changing identity of government agencies to business enterprise.

In late 1995, China Orient contracted Lockheed Martin for a high-power, high-capacity communications satellite called ChinaStar-1. The satellite is built on Lockheed Martin's A2100 platform with 24 C-band and 24 Ku-band transponders units. ChinaStar-1, when placed in orbit, will have an effective coverage of China and Southeast Asian countries in both C- and Ku-band, and part of South Asia and Middle East (C-band only). If the launch is successful, ChinaStar-1 will have an opportunity for market entry after the hiatus caused by the series of initial launch failures.

However, China Orient will be facing competition from other operators such as Sino Satellite Communications, which is also intending market entry at the same time. China Orient also has plans to purchase two more satellites: ChinaStar-2 and ChinaStar-3, but it has not disclosed any dates and technical information. The long-term prospects beyond ChinaStar-1 will likely be affected by the possibility of an over-supplied market, long cycle of satellite life, and off-peak growth in satellite applications.

### **Sino Satellite Communications**

Sino Satellite Communications is a not a member of the consortium controlled by the Chinese Ministry of Radio, Film and Television (MPT). Formed in 1994, Sino Satellite includes agencies such as China Aerospace Corp (CASC), the Commission of Defense Science & Technology, the People's Bank of China, and the Government of

Shanghai. The composition of Sino Satellite clearly suggests an intention to break MPT/ChinaSat domination, with CASC bringing in expertise in satellite research, control and management; the Defense Commission bringing expertise in launching and testing, and People's Bank providing investment guidance. It is also one of the largest potential users of satellite services.

The strategy of Sino Satellite is also significantly different from tradition. It is the first Chinese company to contract with a European satellite supplier (Aerospatiale). Second, the satellite is partially financed by a joint venture between CASC and DASA (Defense and Analytical Services Agency - United Kingdom), which sets a precedent not only in industry financing, but also in China's space development programs. Third, the satellite is designed specifically to target the direct-to-home (DTH) market in the future.

The new satellite is called SinoSat-1 with 24 C-band and 14 Ku-band transponders. The satellite is built on Aerospatiale's Spacebus 3000 platform with Daimler-Benz Aerospace as a subcontractor. SinoSat-1 has a large footprint that covers both China and most Asian countries. Aerospatiale has also supplied a telemetry, tracking and control (TT&C) station located in Beijing. SinoSat-1 provides space segments to all government and business users, including public and private communications networks, as well as thin-route communications and new services such as DTH (direct-to-home) communications and video.

### **Chinese Regional Space Ambitions**

In addition to domestic satellite operations, China has been increasingly active in becoming a regional satellite operator. In December 1995, China and Singapore created a consortium called Asia Pacific Mobile Telecommunications Satellite (APMT). APMT members include CASC, ChinaSat, China Unicom Satellite (a division of China Unicom), Singapore Telecom, and Singapore Technologies Telemedia. The APMT satellite uses L-band for handset-to-satellite, and Ku-band for gateways/operation centers-to-satellite, with a total capacity for 16,000 mobile users. The APMT satellite will be positioned at 110 degrees east, which entails coverage from Japan to Pakistan, and from North China to Indonesia. The initial investment was reported at US \$650 million.

Finally, the future of China's satellite communications market hinges upon how policy will be developed and which direction is taken. Unfortunately, policy development in China is often slow, which causes confusion and anxiety. The key to understanding China's satellite communications market is its policy orientation and the rationale behind it. Since the majority of market participants are governmental entities--including satellite operators and customers--they must behave within the boundary of policies. In this sense, market success in China is measured by how a specific policy is interpreted and used to one's advantage rather than by isolated behavior that may be influenced by market conditions. On the other hand, market dynamics can sometimes act on its own and create exciting opportunities in a particular segment or during a particular period.

## **Chinese Navigation Systems**

Although China has yet to establish a navigation satellite network, research for such a system has been underway for many years, and a future space-based navigation capability is an acknowledged goal. China is using global positioning satellite (GPS) and the Global Navigation Satellite System (GLONASS). Both of these position and navigation satellite systems are being used to improve the accuracy of its weapons and the situational awareness of its operational forces. The Chinese aerospace industry is pursuing the integration of GPS into its new fighter aircraft over the next decade. China's military industrial complex has entered into joint ventures with foreign firms to produce GPS receivers, which may find their way to military weapons.

China Aerospace Corporation displayed a GPS receiver at an exhibition in Beijing in September 1996, and provided brochures advertising both a 12-channel GPS receiver and a 12-channel GPS/GLONASS receiver. One brochure showed a space launch vehicle, suggesting GPS use in missile applications. China produces receivers that can receive GPS and/or GLONASS signals.

Use of GPS updates will enable China to make significant improvements in its missile capabilities. For example, GPS updates will provide the potential to significantly improve missile accuracy through midcourse guidance correction. Moreover, the use of such updates will increase the operational flexibility of China's newer mobile missiles.

## **Feng Yun 2**

China began its geostationary meteorological satellite FY-2 program in 1980. Feng Yun 2 is China's geostationary meteorological satellite, built by the Shanghai Institute of Satellite Engineering (see Figure 8-5). The FY-2 satellite is operationally similar to the geostationary meteorological satellite (GMS) with high resolution stretched VISSR (visible/infrared spin scan radiometer) data (5km IR, 5km WV, 1.25km VIS), low resolution Wefax (analog), DCP (Data collection platform) capability and a new digital S-band fax service (consultative committee international telegraph and telephone (CCITT G3)) for domestic distribution of charts and imagery. The attitude of the satellite is spin stabilized with a speed of 100 rotation/min. The spacecraft is slightly more massive than PRC's DFH-2 communications satellite. The Feng Yun 2 spacecraft bus diameter is 2.1 m, and the total height on-station is about 4.5 m.

In 1994 the long-awaited Feng Yun 2 GEO meteorological spacecraft was launched and positioned at 105 degrees E. The first Feng Yun 2 satellite was undergoing final check-out on 2 April 1994 before being mated to its launch vehicle when a fire and explosion erupted, destroying the vehicle, killing one worker, and injuring 20 others. A second Feng Yun 2 spacecraft was not ready until late 1995.

The Chinese Meteorological Administration (CMA) launched FY-2B to 105 degrees East longitude on 10 June 1997 on a CZ-3 booster from Xichang, and the satellite began regular service late in 1997. On 8 April 1998, FY-2 ceased transmission of images

due to a problem with the S-band antenna on the spacecraft. A second-generation LEO observation satellite called Feng Yun 3 is reportedly under development with substantially advanced multispectral imaging systems.



Figure 8-5. Feng-Yun-2.

### **Zi Yuan CBERS**

Since 1986, China and Brazil have been developing a joint Earth observation spacecraft, commonly referred to as CBERS (China-Brazil Earth Resources Satellite) but also known in PRC as Zi Yuan (Earth Resources). PRC is contributing approximately 70% of the program costs for two spacecraft. The 1,450-kg spacecraft will have overall dimensions of 2 m by 3.3 m by 8.3 m with a 1.1 kW capacity, single solar array and will operate in an 800-km sun-synchronous orbit with a 26-day repeating groundtrack pattern.

The Earth observation payload will include three primary sensors, of which the first two are of Chinese origin. Zi Yuan will also carry a Data Collection System and a Space Environment Monitor.

## **JAPAN**

Japan's postwar space development project work began in 1955 at Kokubunji, Tokyo with a successful horizontal firing experiment involving a pencil-shaped test rocket made by Tokyo University. Later, at the testing range on the Michikawa coast in Akita Prefecture, the "Baby," "Kappa," and other series of rockets were launched. In 1970, after the range facilities were moved to Uchinoura in Kagoshima Prefecture, Japan's first artificial satellite (Ohsumi), the fruit of many trials and failures, went into orbit. Japan became the fourth nation to launch a domestically developed satellite, and soon after, her national space science program took off.

Since then, over thirty scientific and engineering satellites and spacecraft have been launched and inserted into various near-earth and interplanetary orbits. This continuous satellite launch rate enables cutting-edge space science studies such as astrophysics, solar physics, space plasma physics, planetary science, etc. Japan's Space Development

Program is planned and supervised by the Space Activities Commission (SAC), an advisory committee to the Prime Minister. The program is organized into two subprograms of activities; the National Space Development Agency (NASDA) handling practical space applications, and the Ministry of Education's Institute of Space and Astronautical Science (ISAS) handling the field of space science.

In both 1997 and 1998, the budget for the space program shrank. In general, programs that were costly or those that were in the beginning stages of development or considered "risky" received the least funding. Several programs were canceled, or were delayed. The next few years will be crucial for Japan in determining their place in the international space arena.

## **JAPANESE LAUNCH VEHICLES**

### **H-II/IIA Launch Vehicle**

The H-II launch vehicle, the central rocket in Japan's space program, with the capability to launch a two-ton satellite into geostationary orbit, is a two-stage rocket that was developed with Japanese independent technology in all stages. In addition to geostationary (GEO) orbit, it can also be used to launch payloads into low and medium-altitude orbits. For greater economy, it is possible to launch simultaneously two GEO satellites weighing one ton each. The guidance system employs an inertial guidance method, as well.

The H-IIA rocket is designed to meet the various mission demands in the 21st century with lower cost and high degree of reliability, using the technology of the H-II launch vehicle. The H-IIA in its standard configuration is capable of launching a two-ton payload into GEO, as same as the H-II rocket. It can launch a three-ton payload into GEO with the configuration augmented by a large liquid rocket booster (see Figure 8-6). Growth potential up to a four-ton payload launching into GEO is also considered in the design. The vehicle will be launched from Tanegasima Space Center in 2000.



Figure 8-6. H-IIA Rocket.

## **J-1 Launch Vehicle**

The J-I launch vehicle is a three-stage solid fuel rocket with the ability to launch an approximately one-ton satellite into low-earth (LEO) orbit. It was developed in response to expected demands for the launch of smaller satellites. The J-I is the first rocket in Japan to be developed by combining existing rockets. It combines the solid rocket booster (SRB) of H-II developed by NASDA with the upper stage of the M-3S II rocket developed by ISAS of the Ministry of Education.

This has enabled rapid development at low cost. Also compared to a large-scale liquid rocket, a solid rocket makes it possible to greatly reduce launch site operations, which offers a high mobility for the user. To date, J-1 made one launch carrying the Hypersonic Flight Experiment (HYFLEX) in February 1996.

## **JAPANESE OBSERVATION SATELLITES**

### **Maritime Observation Satellite (MOS)**

Japan's first remote-sensing satellite was the Maritime Observation Satellite (MOS-1a). Built by NASDA, it was launched 560 miles above Earth in 1987 aboard a Mitsubishi N-2 rocket from Tanegashima Island Space Center. MOS-1a focuses on the world's oceans, noting color and temperature, and providing ocean data to sixty Japanese organizations and sixteen other countries. MOS-1a also looks at land surfaces when over them, checking on agriculture, fishing, forestry and environmental problems. The satellite has three passive sensors to collect sunlight reflected from the surface of Earth and electromagnetic energy radiated from the planet's surface.

The satellite circles the globe every 103 minutes, completing 14 trips a day and covering the entire Earth every 17 days. MOS-1b, a twin to MOS-1a, was launched in 1990 with two other satellites on one H-1 rocket. MOS satellites are controlled by NASDA's Tsukuba Space Center. Signals also are received by tracking stations at Katsuura, Masuda and Okinawa. NASDA'S Earth Observation Center, established in 1978, is located near downtown Tokyo.

### **Japanese Earth Resources Satellite (JERS)**

The primary mission of the Japanese Earth Resources Satellite (JERS) is earth observation. The satellite was also used to develop Synthetic Aperture Radar (SAR) and optical payloads for future earth observation systems. JERS was the world's first earth resources satellite to have both synthetic aperture radar and an optical sensor for its primary payload. Initially, the antenna for the synthetic aperture radar failed to deploy; this was corrected in April 1992. A data recorder on the satellite can store up to 20 minutes of either synthetic aperture radar or optical imagery data. Three Japanese sites and six foreign sites are able to receive data in real time.

## **Tropical Rainfall Measuring Mission (TRMM)**

The volume of rainfall in the tropics accounts for about two-thirds of total rainfall on the Earth. Acting as the "engine" of the atmospheric cycle, this rainfall has a major influence on climate patterns on a global scale. Tropical Rainfall Measuring Mission (TRMM) is a satellite that measures the amount and distribution of rainfall in tropical and meta-tropical areas. Remote sensing of rainfall by the satellite makes a major contribution to predicting climatic changes on a global scale, providing long-range predictions of abnormal weather created by the El Niño phenomenon, and helping to prevent natural disasters.

TRMM, launched in 1997, is a joint project of Japan and the United States, with Japan responsible for development of the precipitation radar instrument and launch with a H-II rocket, and the U.S. responsible for development of the satellite bus, the four other sensors, and satellite operation. TRMM measures tropical rainfall between 35 degrees North and south latitude, from a 220-mile high orbit. One instrument is a microwave imager which can see through clouds to measure rainfall rate and distribution, cloud and soil moisture levels, land and sea surface temperatures, and sea surface wind speeds. The microwave imager is similar to the special-sensor microwave imager used by the U.S. Air Force in its Defense Meteorological Satellites.

## **Advanced Earth Observing Satellite (ADEOS)**

The Advanced Earth Observing Satellite II [ADEOS-II] is currently under development to help answer questions on the global environment. With this in mind, ADEOS-II will monitor global environmental changes in an environment of international cooperation while continuing and furthering the broad-ranging observation technology created by ADEOS. It was launched in 1996.

ADEOS-II includes sensors developed by NASDA such as AMSR, an advanced microwave radiometer. Additional instrumentation includes: a scattering meter (Sea Winds, NASA/JPL), an improved spectrometer for measuring infrared radiation at the edge of the atmosphere, an earth surface reflection measuring. These are for continuous observation and data collection to help clarify the water-energy cycle. It is also expected to play a major role in defining the climatic mechanisms related to global environmental shifts, such as global warming. ADEOS is Japan's most ambitious Earth-resources program to date.

## **JAPANESE ENGINEERING TEST SATELLITES**

### **Engineering Test Satellite 7 (ETS-7) [Orihime/Hikoboshi]**

Engineering Test Satellite 7 (ETS-7) launched in 1997, is composed of a chase satellite (HIKOBOSHI) and a target satellite (ORIHIME). Its objectives are to carry out experiments to confirm the basic technologies for rendezvous-docking and space robotics.

Research and development are underway to confirm operational technology for orbital operations via data relay satellites.

The ETS-7 conducts the rendezvous-docking and space robotics experiments as shown in Figure 8-7. Comprised of a box-shaped 2480 kg main “chaser” bus and a much smaller square panel-shaped 410 kg “target” satellite, the ETS-7’s two units will separate and recombine in orbit. This will enable NASDA to develop automatic docking systems needed for re-supplying the International Space Station via Japan’s future unmanned space shuttle, HOPE X. The operation of the ETS-7 is conducted from the ground via data relay satellite (TDRS). These experiments on the ETS-7 enable Japan to establish the basic technology for future space activities.

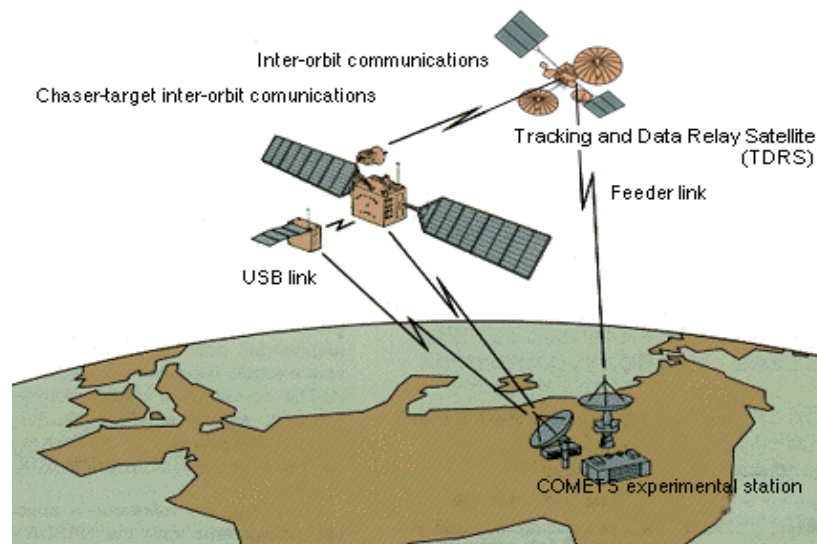


Figure 8-7. ETS-7.

### Optical Inter-orbit Communications Engineering Test Satellite (OICETS)

Optical Inter-orbit Communications Engineering Test Satellite's (OICETS) goal is orbital testing of elementary technology, particularly light beam acquisition, tracking and directional control for optical intersatellite communications--an important element of future space technology. There are plans to conduct experiments together with the ARTEMIS geostationary satellite of the European Space Agency (ESA). The launch of OICETS is scheduled for the summer of 2000.

Light beams traveling for a distance of several ten thousands of kilometers will be accurately tracked. Finely intertwined light beams are expected to be transmitted with high directional accuracy. Communications between geostationary satellites, or between geostationary and low earth orbit satellites are a key technology to support various space activities such as global data reception from earth observation satellites, continued communication links with a manned space station, and on-orbit operations of a space plane. Especially with regard to an optical Inter-orbit communication system, we can expect various advantages such as more compact and lighter communication equipment,



higher data rate and larger communication capacity, and limited risk of interference with other optical communication systems.

A distance between geostationary and low earth orbit satellites could be up to 45,000 kilometers. Optical inter-orbit communication systems would require high power laser devices, high gain optical antennas, and highly sensitive signal detectors. The objective of OICETS is to develop these technology elements, and to conduct their on-orbit demonstrations. Figure 8-8 displays the experiment concept.

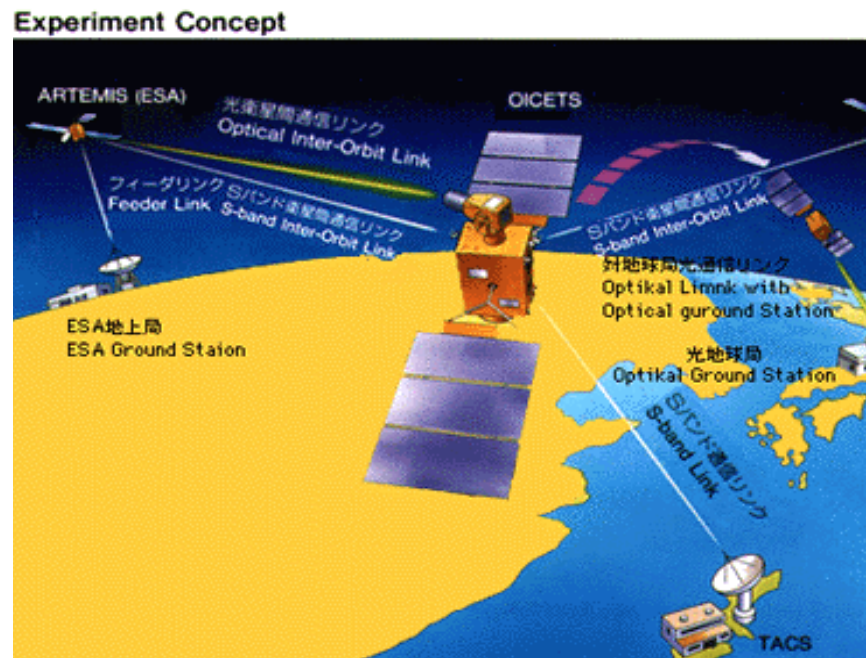


Figure 8-8. OICETS Experiment Concept.

The overall system for optical inter-orbit link experiments will consist of NASDA'S OICETS, Communications and Broadcasting Engineering Test Satellite (COMETS), Tracking and Control Center (TACC) and domestic Tracking and Control Stations (TACSs) and ESA's ARTEMIS and ground stations. The experiments between OICETS and ARTEMIS will be conducted with supports from the ESA ground stations.

### Communications and Broadcasting Engineering Test Satellite (COMETS)

Communications and Broadcasting Engineering Test Satellites (COMETS), a two-ton geostationary three-axis stabilized satellite (Figure 8-9), was created to develop new technologies in communications and broadcasting. Relay satellites in geostationary orbit will be used to develop the following technologies:

- Inter-orbit communications technology for relay of communications.

- Advanced satellite broadcast technology for broadband region-specific broadcasts and high definition television broadcasts using K-band frequency bands.
- Development of advanced mobile satellite communications technology possessing reproduction relay and inter-beam connection functions by employing K-bands and miliband frequencies.

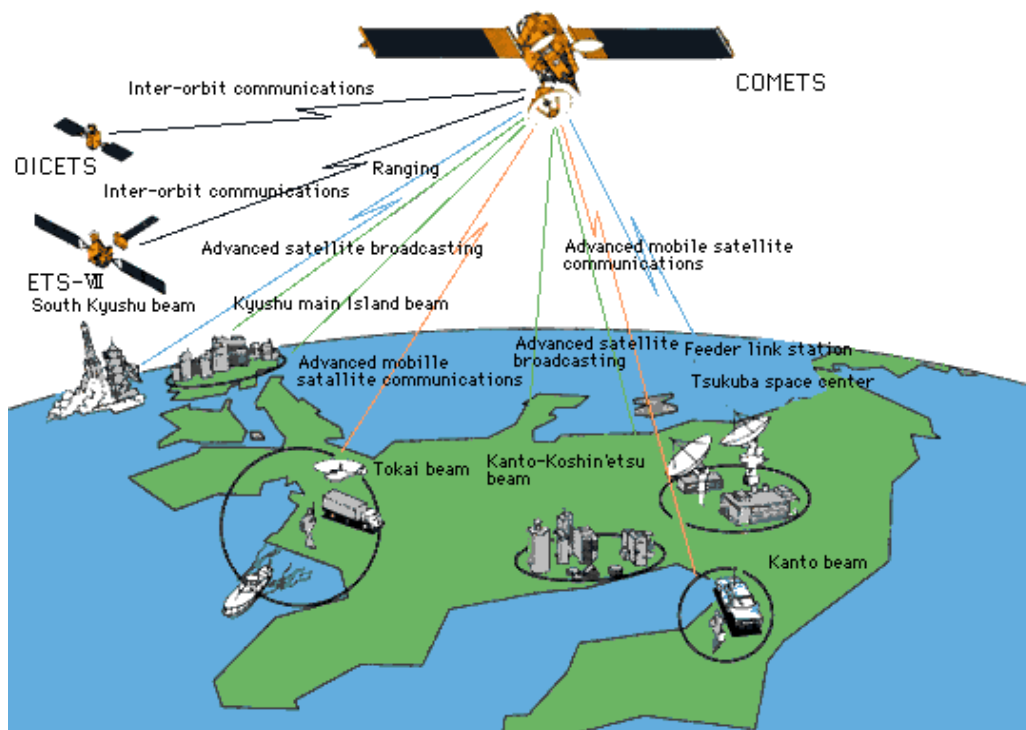


Figure 8-9. COMETS.

## JAPANESE FUTURE PROGRAMS

### H-II Orbiting Plane-Experiment (HOPE-X)

H-II Orbiting Plane-Experimental (HOPE-X) is an unmanned experimental vehicle to establish major technologies for reusable space transportation systems, which can reduce space transportation cost drastically. The development of HOPE-X aims for a flight experiment in 2001. HOPE-X has the size required for practical mission such as supply/recovery of logistics to/from the International Space Station, which will operate early in the 21st century, and transports experiments into orbit. HOPE-X will demonstrate the technologies by flying the flight path similar to those of the practical missions. Moreover, HOPE-X has growth potential to fulfill practical missions by minor improvements. HOPE-X will be launched by single stage H-IIA rocket from Tanegashima Space Center. After separation from the rocket, the vehicle will be boosted and injected into a low earth orbit with the International Space Station.

During testing, the HOPE-X will make one revolution around the earth, the vehicle will de-orbit and reenter the atmosphere. Then it will glide down while controlling its attitude and flight path by RCS and aerodynamic surfaces, approach and land on the runway automatically. During atmospheric flight after reentry, the surface temperature of the vehicle will exceed 1500°C at maximum by aerodynamic heating, and the communication between the vehicle and the ground stations will blackout temporarily due to ionized air. The mission time of HOPE-X is planned to be about 2 hours.

### **Selenological and Engineering Explorer (SELENE)**

The SELENE (Selenological and Engineering Explorer) project was originally scheduled to launch Japan's first lunar probe by a H-IIA rocket around 2003. Due to funding issues, a delay is now expected. Its objectives include collecting data necessary to explain the origin and evolution of the Moon, and developing the technology for soft landing on the Moon. The information will also be used for research on the potential of future utilization of the lunar environment. SELENE is an explorer consisting of a lunar orbit satellite, a Moon-landing experiment vehicle, and a relay satellite.

## **EUROPEAN SPACE PROGRAMS**

The European Space Agency (ESA) was formed in May 1975 by a merger of the European Space Research Organization (ESRO), and the European Launcher Development Organization. ESA has 14 member nations and a cooperative agreement with Canada. All the nations do not participate in every program, but most programs are supported by at least eight nations. Each nation's contributions to an ESA program may vary from about 1 to 60 percent of the total program cost—France, Germany, Italy, and Great Britain are the largest contributors (additionally, all these countries have separate national space programs). It is normal for the contracted work on each ESA project to be distributed among the countries in proportions closely matched to their contributions. This results in more complicated industrial teaming arrangements than exist in the United States. However, teaming arrangements for commercial projects are simpler.

The ESA launched its first remote-sensing satellite on an Ariane space booster (discussed later) in 1991. Soon thereafter, European Remote Sensing Satellite (ERS-2) was launched. ERS-1 and ERS-2 monitor land, sea and coastlines from Earth orbit with an all-weather synthetic-aperture radar. The products range from high resolution photos of Earth's surface to products measuring wind-blown waves on the oceans.

By the year 2000, ESA will have developed and launched several advanced telecommunications satellites as well as payloads flown on non-ESA satellites. In addition, development of a new, small platform usable for various orbits and missions is in the planning stages. These projects will expand the technological base of Europe's space industry and act as a foundation for establishing new services throughout Europe. Certainly the future of the ESA will evolve. The introduction of the Euro monetary unit in

January 1999 was another step in converging and forming closer partnerships in all facets of European economies.

## **EUROPEAN LAUNCHER**

### **Ariane**

Putting an ambitious space program in place requires independent access to Space. The Europeans realized this from the outset, and their efforts took concrete form in July 1973 in Brussels, with the adoption of the Ariane program by the countries who subsequently formed the ESA. Based on proven technologies and a European know-how gained in the various national programs, the Ariane program gave ESA a reliable launcher of its own, and thus its own means of access to space.

The European Ariane rocket, which first flew on 24 December 1979, has become a commercial launcher, taking bookings from many countries to launch their satellites. It was designed from the start specially for putting satellites, e.g. (telecommunications and meteorology), into geostationary transfer orbit, and has lowered costs by regularly launching two at a time.

*Arianespace*, the international company that markets the Ariane launchers, today holds more than half of the launch market, with customers in Europe, the US, Japan, Canada, India, Brazil and elsewhere around the world. As the number of satellites grew, Ariane-1 gave way, to the more powerful Ariane-2 and Ariane-3, and these were in turn superseded, when the Ariane-4s arrived in 1988. As Europe's "space workhorse", Ariane-4 is available in six versions. One of the versions is "bare", and the others fitted (depending on the mass to be put into orbit) with two or four strap-on boosters.

The decision to develop a new heavy-lift launcher was taken at The Hague in 1987 by the ministers of the Member States of the European Space Agency in order to make Europe more competitive in the commercial launch market. Its level of performance and manned flight capability make Ariane-5 considerably different from its predecessors (see Figure 8-10). It consists of a lower section --identical for all missions--and an upper section whose configuration varies according to the mission.

Ariane-5 also has a unique propulsion system. A cryogenic main stage has been developed, powered by a completely new single engine, the Vulcain, which delivers a thrust of around 100 tonnes. Lift-off is achieved by means of two lateral solid propellant boosters, delivering a maximum thrust of 640 tonnes each, which are not ignited until the proper functioning of the Vulcain engine has been verified. Although the technical options for the Ariane-5 program were largely based on the industrial facilities and technical expertise built up in the course of earlier Ariane programs (1 to 4), development of the new launcher constitutes a significant step forward in terms of European industrial know-how.



Figure 8-10. Ariane-5.

## **EUROPEAN TELECOMMUNICATION SATELLITES**

### **Orbital Test Satellite (OTS)**

ESA started development of communications satellites in 1968 and launched its Orbital Test Satellite (OTS) ten years later. The OTS satellite was used for over 13 years by ESA and EUTELSAT, Europe's organization for satellite telecommunications, to provide pre-operational capacity and demonstrate new services: broadcasting to cable feeds and direct-to-home television.

### **European Communications Satellite (ECS)**

OTS was the first three-axis-stabilized Ku-band satellite. Based on the design of OTS, ESA developed and launched four European Communications Satellites (ECS) from 1983 to 1988 for exploitation by EUTELSAT. Two are still in commercial service. Each ECS allowed coverage of the whole European continent for cable television, trunk telephony, specialized services and Eurovision transmissions.

### **Mobile Service Satellites (MARECS)**

Two MARECS (mobile services satellites) were developed by ESA to provide communications with mobile stations, especially ships at sea. Launched in 1981 and 1984, they were later leased for operations to INMARSAT. One of them is still in service today. The L-band payloads, with global coverage, can handle around 50 telephone circuits.

## **Olympus**

The Olympus experimental satellite is a direct-to-home TV broadcasting payload allowing programs to be captured with antenna dishes as small as 30 cm in diameter. Olympus also provided regular High-Definition Television (HDTV) transmissions and capacity for digital broadcasting experiments. Small terminals with antennas of 1m 2.5m used the Specialized Business Services payload for bi-directional communications to exchange data, images and video signals, or for broadcasting to a selected number of viewers (narrowcasting). In May 1991, control of Olympus was accidentally lost. A major recovery action enabled the spacecraft to resume full serviced the following August. After two more years, the experimental mission was concluded when it ran out of fuel.

## **Advanced Relay and Technology Mission Satellite (ARTEMIS)**

Carrying three payloads plus a number of experiments, ARTEMIS (Advanced Relay and Technology Mission Satellite) is being developed for testing and operating new telecommunications techniques. The L-band mobile payload will allow two-way communications, via satellite, between fixed Earth stations and trucks, trains or cars anywhere in Europe and North Africa as shown in Figure 8-11. Satellite systems have no coverage gaps and are therefore expected to occupy up to 10% of the mobile communications market. ESA concentrates on such systems specifically for the European market.

In parallel, ESA is exploring advanced technology to transmit data directly from one satellite to another using radio waves and laser beams. At present, users of Earth Observation satellites in low orbit like ERS-1 and ERS-2 must rely on global networks of ground stations to receive their vital satellite data. But, as information requirements and the number of missions grow, this approach is becoming too slow, expensive, and technically infeasible.

ARTEMIS will carry two payloads for communications directly between satellites, which will receive data from low-Earth-orbiting satellites and transmit them directly to Europe: a laser-optical relay terminal called SILEX, and a double-frequency S/Ka band terminal called SKDR.

ARTEMIS is scheduled for launch in the year 2000 on a Japanese H2A launcher in the framework of a cooperation agreement with the Japanese space agency, NASDA to which, in exchange for the launch of the satellite, ESA will provide data relay capability through ARTEMIS itself. Users of ARTEMIS will include, the French Observation satellite SPOT 4, NASDA's telecommunication satellite OICETS, ESA's ENVISAT, and the International Space Station.

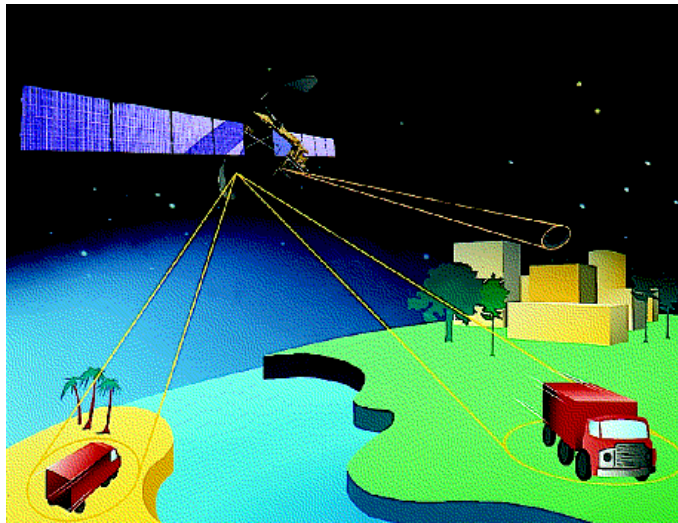


Figure 8-11. ARTEMIS and Mobile Links.

### **Satellite Probatoire de l'Observation de la Terre (SPOT)**

SPOT is an acronym for Satellite Probatoire de l'Observation de la Terre. France launched its first photography satellite, SPOT-1 in 1986 on an Ariane rocket to a 500 mile high orbit. The telescope attached to a camera in the satellite can resolve objects as small as 30 feet. SPOT-2 was launched to orbit in 1990. The visible and infrared light telescopes in the SPOT satellites were designed to map the globe, study land use, investigate renewable resources on forests and farm lands, and explore for minerals and oil.

SPOTs are owned by an organization of private and government interests in France, Belgium and Sweden. They are operated by the Centre National D'Etudes Spatiales (CNES), the French national space agency. The SPOT satellite program is very active and robust.

### **EUTELSAT SATELLITE SYSTEM (EUTELSAT I Through II-F Series - 1)**

Not only do both INTELSAT and INMARSAT (international telecommunications satellites) provide coverage, but the ESA has developed the European Telecommunications Satellite Organization (EUTELSAT)-1 series as part of the ECS program. Once launched and checked out in orbit, each satellite was handed to EUTELSAT for commercial operations. The satellites are maintained in orbit by ESA from its Redux earth station in Belgium. EUTELSAT-1 was a three-axis-stabilized satellite with suntracking solar arrays. It is composed of a service module and a communication module. The communication module included the Earth-viewing, north and south faces of the body.

The initial contract in 1986 for the EUTELSAT II series called for three satellites with an option for five additional satellites. A fourth satellite was ordered in June 1987, a fifth in March 1989, and a sixth in September 1990. The fourth and fifth EUTELSAT II



satellites were modified to extend the widebeam coverage as far as Moscow and surrounding area. EUTELSAT II-F6, renamed (HOT BIRD I) has been modified for collocation with EUTELSAT II-F1. The EUTELSAT II had 16 transponders.

### **Hot Birds**

In 1992, EUTELSAT had the sixth EUTELSAT II modified to optimize it for broadcast of analog and digital television. It gained the nickname “Hot Bird”, which later became the standard name. The Hot Birds replaced the high-powered Europsat television broadcast.

After Hot Bird 1’s launch in 1995, Hot Bird 2 took off in 1996, Hot Bird 3 in 1997, Hot Bird 4 in February 1998, and Hot Bird-5 was launched successfully in October 1998, and replaced EUTELSAT II-F1. Hot Bird 5 (Figure 8-12 displays its receive antenna) has 22 transponders. The constellation today broadcasts 40 analogue and nearly 300 digital television channels and reaches more than 70 million cable viewers in Europe, Africa and the Middle East. This is one of the largest broadcasting systems in the world today.

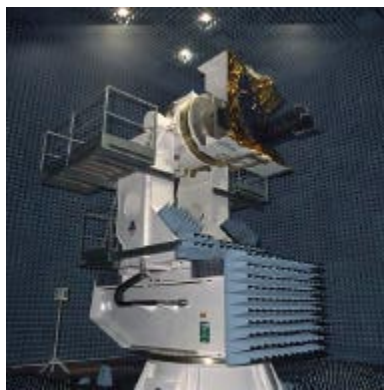


Figure 8-12. HOT BIRD 5’s Receive Antenna.

### **W Series and SESAT**

Also launched in October 1998, EUTELSAT’s W2 satellite is capable of handling all the traffic carried by the older EUTELSAT II-F3. A new generation of telecommunications satellites will take over service from the EUTELSAT II series in 1999/2000. These new satellites will allow for the expansion of telecommunications services as well as supply some television services to other markets. The new satellites feature steerable antennas and an extended coverage of the Middle East. They are equipped with 24 transponders of 90 watts and their minimum lifetime will be 12 years. There were initially three satellites in the constellation.

A contract for the fourth telecommunications satellite will be finalized with NPO-PM of Russia, for launch in early 1999. Positioned at 36 degrees East, EUTELSAT’s most easterly orbital position, the satellite’s 18 transponders will enable EUTELSAT to develop



new markets in far eastern Europe and central Asia, as well as provide full interconnectivity with western and central Europe.

### **European Global Navigation Satellite System**

Satellites will play a major role in the deployment of the Global Information Infrastructure (GII) allowing, worldwide access to multimedia which is fast developing and embraces in one single digital form all types of information (video, audio, data). ESA has initiated in parallel, with the European Union manufacturers, operators, and service providers, a program which is intended to place Europe in a favorable position for the Multimedia global competition.

Two satellite-based navigation systems for the high precision positioning of aircraft, ships, trucks, etc., are operational today: the US's Global Positioning System (GPS) and Russia's Global Navigation Satellite System (GLONASS). Both are military networks, each based on a constellation of 24 operational satellites. However, the GLONASS network is severely degraded and will probably never maintain a 24-satellite constellation.

Europe has decided to implement a satellite-based navigation system in a two-step approach. The first step will lead to a European overlay navigation system (EGNOS) using the two existing navigation satellite constellations (GPS and Glonass). The second step is intended to enable Europe to become a major partner in setting up a civilian satellite system by 2010. This system will be available to the aeronautical community for all its navigation requirements, including precision landing. Maritime and land mobile users will also greatly benefit from the system. A European tripartite group consisting of ESA, the European Union and Eurocontrol is currently coordinating the navigation activities.

### **RUSSIAN (FORMER SOVIET) SPACE PROGRAMS**

The first decade of space exploration was marked by many Soviet and American firsts. In October 1957, the Soviets launched Sputnik I, the first artificial satellite to circle the Earth. A month later, Sputnik II rocketed spaceward carrying a dog, Layka, the first space traveler to orbit our planet. In following years, dozens of American and Soviet satellites were launched, with several probes exploring even more distant regions of space.

The real challenge of space exploration was to place people into a stable orbit around the earth, and then move them toward the moon. The first human to orbit the Earth was Soviet cosmonaut, Yuri Gagarin. He flew in the Vostok I spaceship for one circuit of the globe in April 1961. During the 1960s, many Soviet cosmonauts and American astronauts mastered space flight. Only U.S. astronauts achieved the goal of landing on the faraway Moon. In 1975, Russia and the United States worked together to link their respective spaceships above Earth the U.S. Apollo and the Soviet Soyuz 19 a historic first in space cooperation.

Today, U.S. space shuttles routinely take astronauts into Earth's orbit to experiment in microgravity. The Russians use Space Station Mir to study the effects of long duration of weightlessness on the cosmonaut space travelers. Built of many modules, the Mir was first launched in 1986. On one expedition aboard the Mir, the cosmonaut team of Musa Manarov and Vladimir Titov spent a total of 366 days, 18 hours and seven minutes in space the current world's record. In recent times, the Russians have opened up their space program to cooperation with other nations. They also want to commercialize their space program to help reduce its cost. In upcoming years, U.S. astronauts and Russian cosmonauts will work together in space, forging friendships will build the International Space Station and possibly lead to other missions in outer space.

## **LAUNCHERS**

### **Soyuz Booster Family**

The R-7 Soyuz missile was designed and specifications written in 1953, serving as the basis for the most famous family of boosters ever developed (see Figure 8-13). By 1954, engine development was underway. In 1955, the testing launch site at Baykonur was selected. The booster was built at the Kuznetsov factories at Kuybyshev. In April 1956 the first R-7 rockets were finished and ready for testing and engine testing began. From August, until Dec. 1956, launch equipment for the R-7, was installed at Baykonur. After three failures, the first successful flight of the R-7 occurred in 1957. The rocket test flight terminated at the Kamchatka peninsula. The second successful flight was on Sept. 7, 1957, with the Soviet Premier, Nikita Khrushchev viewing the launch.



Figure 8-13. Soyuz Launch Platform.

By 1988, more than 1200 R-7 boosters had been launched. It was reported that the A-2 assembly line was shut down in 1985 after years of phasing out by the Tsyclon booster for military launches and amid plans for using the Soviet shuttle for manned missions. Boosters were stockpiled for use several years later. At Baykonur, the Soyuz boosters were assembled horizontally in an assembly building.

The Soyuz has been dubbed by some the 'Machine of the Century' for its major contributions to history and its long-lived design.

### **Sputnik Satellites and Launch Vehicles**

The first Soviet satellite program consisted of four Sputnik (see Figure 8-14) satellites. However, the Sputnik launched between Sputnik 2 and 3 failed to reach orbit. Sputnik 1, launched on October 4, 1957, was designed to send radio signals to Earth and determine the density of the upper atmosphere. However, it only transmitted signals to Earth for a short time after launch. Its orbit decayed and it fell to Earth on January 4, 1958.

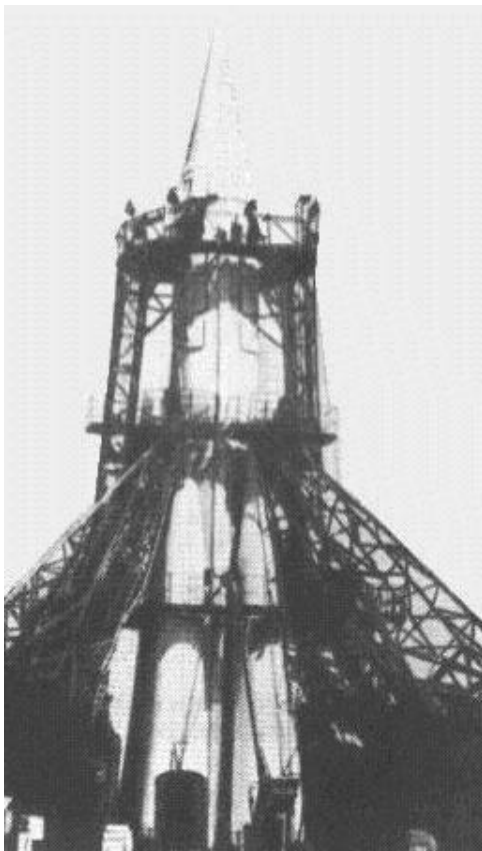


Fig. 8-14. Sputnik launch vehicle on pad.

Sputnik 2 (Figure 8-15) was launched on November 3, 1957, and carried aboard it a dog, Layka shown in Figure 8-16. Biological data was returned for approximately a week (the first data of its kind). However, there was no safe re-entry possible at the time, and Layka was put to sleep after a week in orbit. The satellite itself remained in orbit 162 days.



Fig. 8-15. -  
Sputnik 2.



Fig. 8-16.  
Layka as  
seen on  
Russian TV.

Sputnik 3 (Figure 8-17) was launched on May 15, 1958. It may have originally been intended as the first launch in the Sputnik program. However, the Russians decided to be more cautious in their launch schedule. Sputnik was designed to be a geophysical laboratory, performing experiments on the Earth's magnetic field, radiation belt, and ionosphere. It orbited Earth and transmitted data until April 6, 1960, when its orbit decayed.



Fig. 8-17. Sputnik 3.

All Sputniks were launched using the SS-6, or Sapwood rocket. The SS-6 was originally designed as a ballistic missile, and had its upper stage modified slightly to hold the Sputnik payload. It had two stages, four strap-on booster rockets for the first stage, connected to the second stage rocket. Total mass at launch for Sputnik 3 was 142,169 kilograms, with a length of 29.17 meters. The primary stage used RD-107 engines, which provided 100,000 kg of thrust. Both stages were powered by liquid oxygen, (LOX)/Kerosene.

#### **Luna Probes and Launch Vehicles**



*Luna 1*



*Luna 2*



*Luna 3*

Fig. 8-18. Luna Space Vehicles.

Following the Sputnik launches, Russia launched a series of satellites at the moon between 1958 and 1960 called Luna (Figure 8-18). However, only three of these satellites fulfilled their missions. This was partially the fault of the launch vehicle.

- Luna 1 was intended to impact on the moon; however its trajectory missed the moon, and it flew past instead, eventually falling into a solar orbit (becoming the first spacecraft to do so).
- Luna 2, performed the first impact on the moon (the first man-made object to reach another world), east of the Marc Serenitatis. It carried with it a plaque of the Soviet Coat of Arms.

- The final Luna probe, Luna 3, circled around the moon, and took the first photographs of the moon from its orbit. It also carried instruments to study the physical and radiation environment of lunar space.

### **Vostok Spacecraft, Crews and Launch Vehicles**



Figure 8-19. Vostok Spacecraft.

The Vostok spacecraft (see Figure 8-19) was a small one-man spherical descent module. The module was mounted on top of an instrument module containing the engine system. The cosmonaut was strapped into an ejection seat, from which he would exit the descent module upon re-entry, from an altitude of approximately 7 kilometers. This module was later modified for the Voskhod program, and in other unmanned satellite programs.

During Vostok 1, Gagarin was not given control of his craft. This was because it was unsure how a cosmonaut would respond to weightlessness, and that he might endanger his craft if he had control. However, he suffered no ill effects, and ejected some 20 minutes before the craft's landing. This fact was hidden by the Soviet government for some time, as it was required for a pilot to remain in his craft from launch to landing to qualify as a space flight. Vostoks 3 and 4 were launched within a day of each other, and fell into similar orbits. They ultimately passed within 6.5 km of each other, but were unable to perform a rendezvous. Likewise, Vostok 5 and 6 were launched within two days of each other, again into similar orbits. They passed as close as 5 km to one another. On board Vostok 6 was the first woman in orbit, Valentina Tereshkova.

The Vostoks used the SL-3 variant of the SS-6 Sapwood rocket. The spacecraft was mounted in roughly the same way as the Luna probe housing. The SL-3 had a total mass of 287.03 tons at launch, being 38.36 meters in length. It had three stages, the first stage being four breakaway boosters, strapped on to the second and third stages. The first stage provided 102,000 kg of thrust. All three stages were LOX/Kerosene powered.

## **Voskhod Spacecraft, Crews and Launch Vehicles**



Figure 8-20. Voskhod Spacecraft.

The Voskhod (see Figure 8-20) program came into being following the termination of the Vostok program, and with problems delaying the Soyuz program. It used the Vostok descent module, enlarged to 5.3 tons for Voskhod 1 and 5.7 tons for Voskhod 2. A roughly cylindrical housing was fitted over the descent module/instrument module for launch (this was standard for manned spacecraft launches). There was also a retro-rocket installed on both Voskhods, and Voskhod 2 also had an airlock installed to allow a spacewalk. The retro-rocket was to be used in descent, allowing for a soft landing (as there was no longer room for ejection seats). Voskhod 2 had an airlock fitted to the side of the craft, which was folded against the side during liftoff. It was used by Alexei Leonov to take the first tethered walk in space, attached to the inside of the airlock by an umbilical cable. His spacewalk lasted 12 minutes. A larger rocket was required for the Voskhod spacecraft, and so the SL-4 booster rocket was used. However, the SL-4 was intended for the larger Soyuz spacecraft, and would launch the Voskhods into too high an orbit. Because of this, a second retro-rocket was fitted onto the front of the Voskhod descent module, allowing the Voskhod to decrease its orbit if the primary rocket failed.

## **Soyuz Spacecraft, Crews and Launch Vehicles**



Figure 8-21. Soyuz Spacecraft.

The Soyuz (Figure 8-21) 2-9 craft followed in the footsteps of the Vostok and Voskhod crafts. The instrument module had a pair of solar panels to provide the craft with power. A KTDU-35 engine system was used for propulsion. The total mass of the craft averaged around 6 tons, with a maximum of 6,646 kg.

Following Soyuz 9, the Soviets announced that they were changing the goals of the Soyuz program. They would hereafter focus on orbital mission involving the Salyut space stations. Soyuz 10-40 were used to ferry cosmonauts to the Salyut Space Stations, and Soyuz-T 2-4 were used to ferry cosmonauts to the Salyut 6 Space Station. The Soyuz craft were modified to act as ferries. They flew short missions, acting as testbeds for the new format following the Soyuz 11 disaster, in which the airlock failed on re-entry, killing the crew. The Soyuz-T were a heavily modified version of their Soyuz ferry predecessor. The descent module had been enlarged to allow three cosmonauts in pressure suits. The orbital module was largely unchanged. The instrument module included a new computer system (which seems to still lag behind Western spacecraft systems), and a new and improved propulsion system. The solar panels were returned, with a wingspan of 10.6 meters. Average mass was 6,850 kg.

The Soyuz SL-4 modified Sapwood rocket continued to be used throughout the Soyuz missions following their use with the Voskhods. The dimensions of the rocket were virtually unchanged from the model used with the Voskhods.

### **Salyut Space Stations, Crews and Launch Vehicles**



Figure 8-22. Salyut Spacecraft.

The Salyut design (Figure 8-22) has remained largely unchanged, up to the Mir station core, with the main changes being upgrades in technology. The Salyut 1 station was launched on April 19, 1971. It carried with it seven experimental work stations. Of particular interest are the historical Salyut 1, 3, and 4.

Salyut 1 was only inhabited by one Soyuz team. The crew was unable to dock and enter the space station. Soyuz 11 docked successfully, inhabiting the station from June 7-29, 1971. However, the descent module's hatch was jerked open during re-entry, killing the crew.

The Salyut 1 station was launched using a Proton SL-13 vehicle. The SL-13 was designed in 1965 as a more capable follow-on to the two-stage SL-9; its first flight was in 1968. The basic design of the Proton is similar to its manned mission counterpart, the SL-4. However, the SL-13 is much larger, with a total mass at launch (numbers from Salyut 6 launch) of 697.1 tons, and total length of 59.8 meters. The first stage is four breakaway boosters, mounted around the second and third stages. The first stage uses RD-253 engines, which provide 167,000 kg of thrust.

Salyut 3 was the first military space station launched by Russia. It was launched on June 24, 1974, attaining an altitude of 219-270 km. Its final orbital altitude was 268-272 km. Salyut 3 had a total mass of approximately 18-19 tons. It had two solar panels laterally mounted on the center of the station, and a detachable recovery module, for the return of research data and materials.

Salyut 4 was Russia's first civilian space station. It was launched on December 26, 1974. It had an approximate mass of 18-19 tons. There were three steerable solar panels mounted 2 laterally, one dorsal longitudinally on the center of the craft. Each panel was about 3 meters by 7 meters in size.

### **Progress and Progress-M Spacecraft and Launch Vehicles**

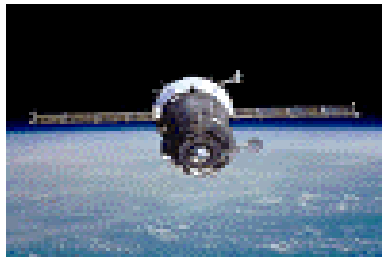


Figure 8-23. Progress Spacecraft.

In order to allow the second-generation Salyut stations (and later the Mir station core) to continue orbital maneuvers, unmanned Progress (see Figure 8-23) freighters were capable of carrying about one ton of propellant for transfer to the Salyut tanks. This was carried in four tanks: two tanks for the nitrogen tetroxide (oxidizer) and two tanks for the UDMH (unsymmetrical dimethylhydrazine- fuel). These tanks were situated in the space where a descent module would be carried on a Soyuz mission, together with a bottle of high pressure nitrogen gas.

The Progress spacecraft is about the same length as a Soyuz. It carried the Igla rendezvous and docking system. They had a mean mass of 7,018 kg. Progress can carry 1,400 kg of cargo in the orbital module and 1,000 kg of propellant for Salyut/Mir. Progress was often used as a space tug of sorts; its Soyuz KTDU-35 engine being fired to raise the orbit of the Soyuz-Salyut-Progress orbital complex.



The Progress-M replaced the older Progress craft in 1989. It now features the Kurs rendezvous and docking system, used aboard the Soyuz - TM craft. They can carry up to 2,580 kilograms (5,700 pounds) of cargo. Progress-M spacecraft can be equipped with small, ballistic re-entry capsules named Raduga for the return of research materials and films from the station.

### **Mir Space Station, Crews and Launch Vehicles**

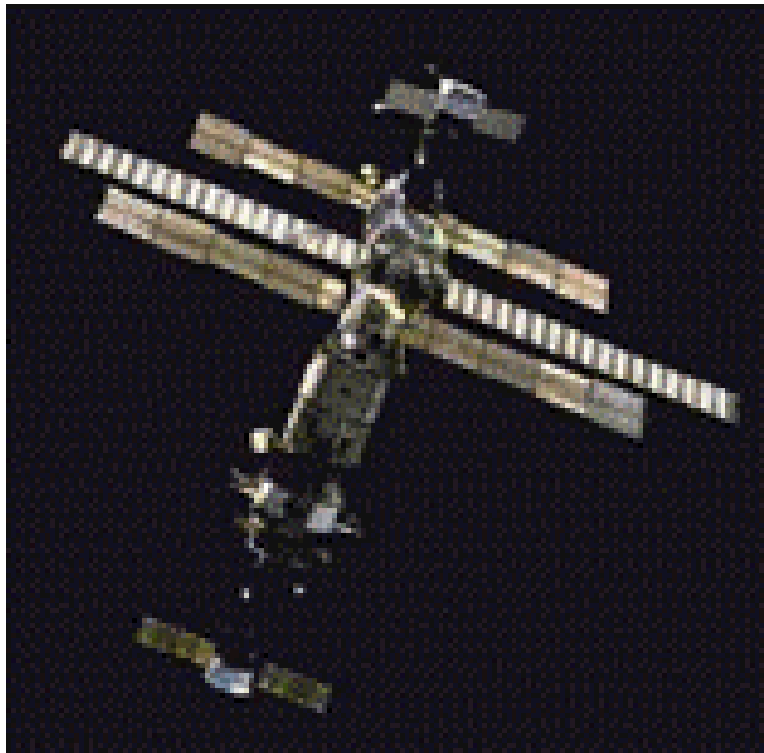


Figure 8-24. Mir Spacecraft

The word, Mir, can be translated in several ways. The official translation for the space station is 'peace', but Mir (see Figure 8-24) can also be translated as commune or village. The base unit of the station was launched on February 20, 1986. The Core Module provides basic living services and scientific research capabilities. It has two axial docking ports for Soyuz-TM manned transports and automated Progress-M supply ships, plus four radial berthing ports for expansion modules. It has a pressurized volume of 90 cubic meters ( $m^3$ ), and three solar panels, two lateral and one longitudinal, with an area of 76 square meters ( $m^2$ ).

Control on the station is highly automated, only 13% of operations require manual intervention. There are 900 displays and indicators in Mir and an average 350 in each additional module. It is estimated that if automatic control failed, the crew of 2 could maintain 65% of normal functions in Mir's 23 major subsystems. Each day, 3-4 hours are spent in communications, 3-4 maintaining life support, 5 hours working on the experiment program. Research cosmonauts allocate 60% of their time to the experiment program.

Routinely 7-8 types of experiment projects are operated daily. Accordingly the researcher needs less knowledge of station systems. Researchers have an estimated 5-10% of the knowledge a commander retains.

Mir is equipped with a multiple docking adapter with 2 docking drogues and 3 blank hatches in place of the transfer compartment on a normal Salyut. These additional docking ports would be used for specialized modules weighing up to 21,000 kg. each. The final weight of Mir was 100,000 kg. The forward port also is equipped with the new Kurs docking system for use with new orbital modules and the Soyuz TM. The Kurs docking system eliminates the need for the space station to be orientated toward the approaching spacecraft. The Progress uses the Igla system, which formerly required Mir to be pointed toward it. This maneuver required use of large amounts of attitude propellant, approximately 190 kg. Procedures were revised by the time of flight of Progress 33 which cut that amount in half. Over the first 3 years of Mir's operations, the improved attitude control and docking systems allowed 24000 kg. of cargo to be flown to Mir instead of propellant.

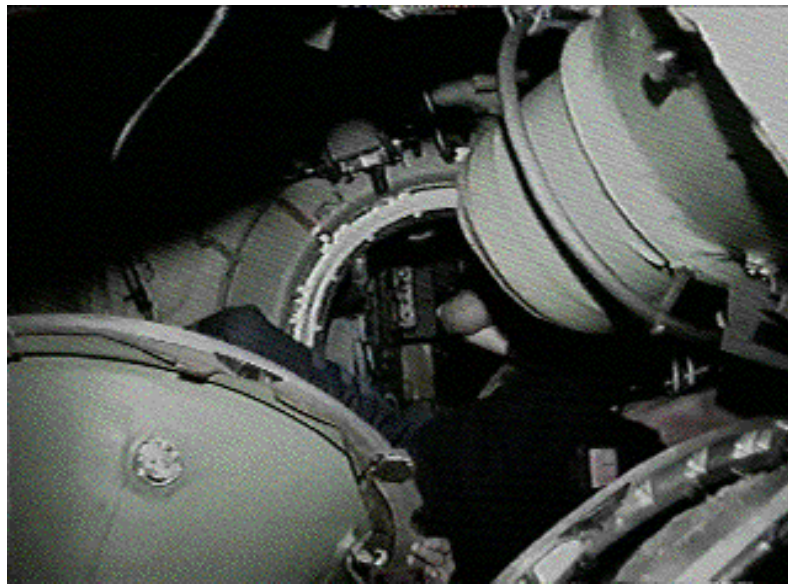


Fig. 8-25. The Mir Multiple Docking Adapter.

The station is divided into two main sections, the work or control section and the living section. Forward of the work section is the docking module and airlock. Any of the hatches on the docking adapter (see Figure 8-25) can be used for extravehicular activity. The station's flight controls are located in the work section end of the station. Figure 8-26 displays a schematic of the layout of Mir.

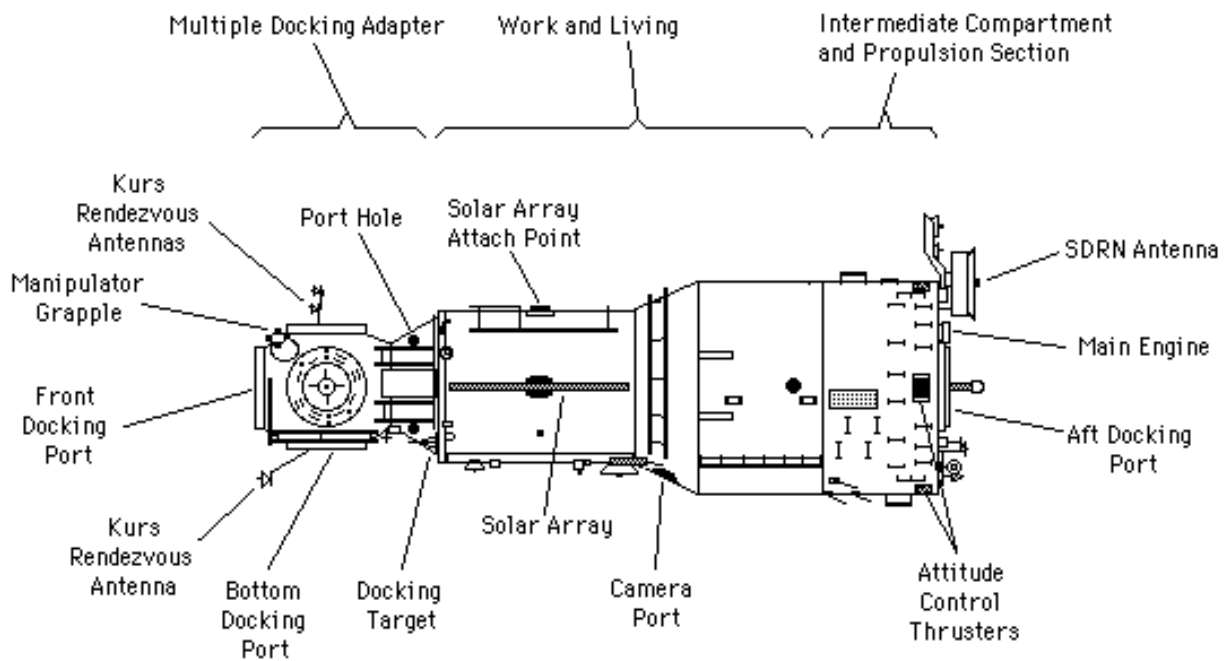


Fig. 8-26. Mir Schematic.

Mir is controlled by seven computers of the Strela system using new components, such as integrated circuits and other miniature electronic devices. A digital data bus provides connectivity between the computers and the station's systems and experiments. The computers are programmed from the ground to operate the station and experiments. The computer is capable of maintaining the station's orientation indefinitely without human intervention. The space station controls include an optical sight and a portable orientation control stick. The environmental system provides a greater ventilation capability than the previous Salyut's. The Vozduyk molecular sieve system vents carbon dioxide directly into space.

Most of the station's volume consists of the living section. The galley and folding table are similar to Salyut equipment with built-in food heaters for a crew of two. For the crew's entertainment and instruction, a video tape recorder and a library of tapes are available for their use. The sleeping compartments each have a folding chair, mirror, porthole and sleeping bag. Next to the left side compartment is a small refrigerator that could hold 40 kg. of food. The living compartment walls are covered with elastic straps to secure items and the general lighting is built into the ceiling. Handrails run the length of the walls and ceiling. There is only one scientific and trash airlock.

## **OTHER FOREIGN SPACE TECHNOLOGY / PROGRAMS**

### **CZECH REPUBLIC**

#### **Scientific-Magion**

For nearly 20 years the Geophysics Institute (renamed the Institute of Atmospheric Physics in 1994) in Prague has specialized in the development of very small scientific satellites. The Czechs designed these spacecraft to investigate the complex nature of the Earth's magnetosphere and ionosphere. These satellites, called Magion, were the forerunners of a category known as microsatellites. Magion satellites are highly sophisticated spacecraft designed for state-of-the-art geophysics exploration.

Developed under the former Interkosmos program, Magion satellites were launched as piggyback spacecraft designed to carry out their experiments in concert with a mother satellite. Magion 1, with a mass of only 15 kg, was launched with Interkosmos 18 in 1978 to monitor low frequency propagation in low earth orbit.

Magion 2 was launched in 1989 with Interkosmos 24 to investigate very low frequency propagation in the magnetosphere and their interaction with energetic particles in the Earth's radiation. Magion 2 also introduced the current Magion base configuration with a mass of approximately 50 kg and a diameter of 0.6 m. The octagonal bus is equipped with four small solar arrays as well as body-mounted solar panels. Magion 2 also carried a Soviet Pulsar maneuvering system to regulate the distance between the sub-satellite and its companion spacecraft, although on this mission, the system malfunctioned.

Magion 3 continued the work begun by its predecessor after launch in 1991 with Interkosmos 25 under the APEKS (Active Plasma Experiment) program. Essentially identical to Magion 2, Magion 3 recorded the effects in the magnetosphere of electron and Xenon ion beams injected by Interkosmos 25. The Pulsar engine performed well on this mission which lasted nine months.

Two more Magion spacecraft were prepared in conjunction with the Interbol project which will employ two pairs of spacecraft (mother-daughter) to investigate the magnetosphere tail and aurora zones, respectively.

### **INDIA**

#### **India and Space Transportation Systems**

Following on the heels of the first successful launch of its Augmented Satellite Launch Vehicle (ASLV) in 1992, India tested the more capable Polar Satellite Launch Vehicle (PSLV) during 1993-1994. The launcher achieved success on the second attempt. Coupled with another ASLV mission in 1994, India's three launch attempts in the two-year

period represented its most active campaign since its indigenous space program began in 1979. India's substantially larger Geosynchronous Satellite Launch Vehicle (GSLV) will continue to launch satellites for the next decade.

All Indian space launches are conducted from the Sriharikota High Altitude Range (SHAR) on Sriharikota Island off the East Coast of India in the Bay of Bengal. The original SLV-3 launch complex was converted to support the ASLV. Two new complexes with one pad each to the south were selected to support the PSLV and GSLV.

### **India and Satellite Communication Systems**

India first experimented with geosynchronous telecommunications relays in 1981 and now has active spacecraft in GEO. Moreover, the launch of INSAT 2A in July 1992, marked the debut of India's first domestically built operational GEO spacecraft. In a departure from most nations, India's GEO platforms combine a communications mission with that of Earth observation. India now maintains a commercial GEO communications network.

### **India and Earth Observation Programs**

Earth observations have played a prominent role in the majority of Indian satellites launched to date. Two of the three space launches attempted by India during 1993-1994 carried Earth observation spacecraft under the Indian Remote Sensing Satellite (IRS) program; IRS-1E in 1993 and IRS-P2 in 1994. This followed the launch of three Indian remote sensing spacecraft (by India, the USSR, and ESA) during the previous 2-year period.

## **INDONESIA**

### **Palapa and Future Indonesian Communication Satellite Systems**

Since 1976 Indonesia has operated a national GEO telecommunications network based on U.S.-made Hughes, spin-stabilized spacecraft. These second-generation Palapa spacecraft have an on-station mass of 630 kg and have all been launched by Delta boosters. (The U.S. Space Shuttle originally launched Palapa B2R as Palapa B2 in February 1984, but its perigee motor malfunctioned, leading to a Shuttle retrieval in November 1984. The spacecraft was then refurbished and relaunched as Palapa B2R.).

The Palapa B series of satellites carry 30 6/1 4 GHz transponders (including six spares) to support telecommunications services throughout Southeast Asia. The design lifetime of the spacecraft is eight years. In 1991 the aging Palapa B1 satellite (June, 1983) was sold to Pasifik Satelit Nusantara (PSN) for a new mission to provide commercial services to the Pacific Rim region.

To handle the next generation of Palapa satellites, Palapa C, Indonesia in early 1993 established PT Satelit Palapa Indonesia (Satelindo) of Jakarta, a commercial firm with the PT Bimagraha Telekomindo the majority shareholder, to manage the Palapa C program and to secure additional investment funding. PSN is also assisting in the Palapa C program with communications services expertise.

The Palapa C series will employ Hughes' HS-601 spacecraft with 34 active transponders: 24 (with six spares) C-band, 6 (with two spares) extended C-band, and 4 (with two spares) Ku-band. The on-station mass of the satellite at beginning of life will be 1,775 kg with a design lifetime of at least 12 years.

On the horizon are two new GEO commercial communications networks. The Indostar system will provide direct broadcast television and radio services specifically for Indonesia. A Jakarta consortium, PT Media Citra plans to launch up to four American-built (International Technologies, Inc.'s Star spacecraft). The spacecraft will have an on-station mass of only 430 kg at the beginning of life with a design lifetime of at least seven years. The payload will consist of three S-band transmitters for television broadcasts and two L-band transmitters for radio services.

## **IRAN**

### **Communications-Zohreh**

Since the 1970's, Iran has considered establishing a GEO communications satellite network. After several abortive attempts, Iran reached a tentative agreement in 1993 to obtain a pair of Russian satellites for its Zohreh system. The Zohreh system will provide both L-band (INMARSAT-compatible) and Ku-band (14 transponders) links. The 1,850-kg spacecraft are to be furnished by Alcatel Espace and Aerospatiale with design lifetimes of 10 years. In the meantime, Iran is leasing Ku-band capacity on INTELSAT spacecraft.

## **ISRAEL**

### **Launch Vehicle-Shavit**

Israel's Shavit (Comet) launch vehicle first flew on 19 September 1988, placing the Ofeq 1 engineering technology satellites into LEO. The third flight of Shavit was postponed in early 1994 until 1995, in part, due to budgetary constraints. Shavit is a small, 3-stage, solid propellant booster based on the 2-stage Jericho 2 ballistic missile and developed under the general management of Israeli Aircraft Industries and in particular its MBT System and Space Technology subsidiary. Israel Military Industries produces the first and second stage motors, while another contractor is responsible for the third stage motor.

Shavit boosters are launched from an undisclosed site near the Palmachim Air Force Base on the coast of Israel south of Tel Aviv. The facility is also sometimes referred to as Yavne. To prevent overflight of foreign territory, Shavits have been launched on a northwest trajectory over the Mediterranean Sea, passing over the Straits of Gibraltar at the west end of the Mediterranean. This procedure significantly reduces the payload capacity of the launch vehicle and severely limits potential operational orbits.

### **Israel and Communication Satellite Systems**

By 1994, Israel had launched only two small experimental LEO satellites. The country then launched its first GEO spacecraft in 1995 on board an Ariane vehicle. Developed by Israel Aircraft Industries with assistance from DASA and Alcatel Espace, the 500-kg-class AMOS (Affordable Modular Optimized Satellite) carried 7 Ku-band transponders (plus two spares) for Eurasian communications services.

### **Israel and Earth Observation Systems**

By the end of 1994, Israel's fledgling space program had produced only two, short duration, LEO satellites of a primarily engineering nature. The 1994 launch of a 55-kg, 45-cm cube micro satellite named Techsat (a.k.a. Gurwin) occurred in 1996. Techsat was later manifested for the inaugural launch of the 5-stage Russian Start booster. Designed and built by the Israel Space Agency, Haifa's Technion Institute, and others, Techsat was outfitted with a simple charged couple device (CCD) television system for Earth observation purposes.

## **KASAKHSTAN**

### **Kazakhstan and Piloted Space Missions**

Although Kazakhstan has yet to establish a formal man-in-space program, five of its natives have flown in space, accumulating more than 650 man-days of experience. T.O. Aubakirov in 1991 was the fourth Kazakh to be launched into space but was the first to officially represent his homeland rather than Russia in general. Two Kazakh astronauts, T.A. Musabayev and A. S. Viktorenko, conducted missions on the Mir space station during 1994 under the Soyuz TM-19 and Soyuz TM-20 programs, respectively.

## **LUXEMBOURG**

### **Communications-Astra**

The Luxembourg-based Societe Europeenne des Satellites (SES) provides telecommunications services to most of Europe via American-manufactured spacecraft. The Astra network was doubled during 1993-1994 and at the end of 1994 consisted of four

satellites, all launched by Ariane. The Astra spacecraft carry 16 Ku-band transponders, but those on Astra 1B are higher power (60W versus 45W).

## **MALAYSIA**

### **Communications-MEASAT**

A long-time user of INTELSAT and Indonesian communications satellites, Malaysia decided in 1991 to establish a domestic GEO communications system with the aid of US-built spacecraft. Two Malaysia East Asia Satellites (MEASATs) were launched in 1996. The Hughes HS-376 spin-stabilized spacecraft features several improvements over its class, including gallium arsenide solar cells, greater payload power availability, and a new lightweight, high-gain antenna. The MEASAT 1 communications payload consists of 12 C-band and four, high power (110 W) Ku-band active transponders. The design lifetime is 12 years.

## **NORTH KOREA**

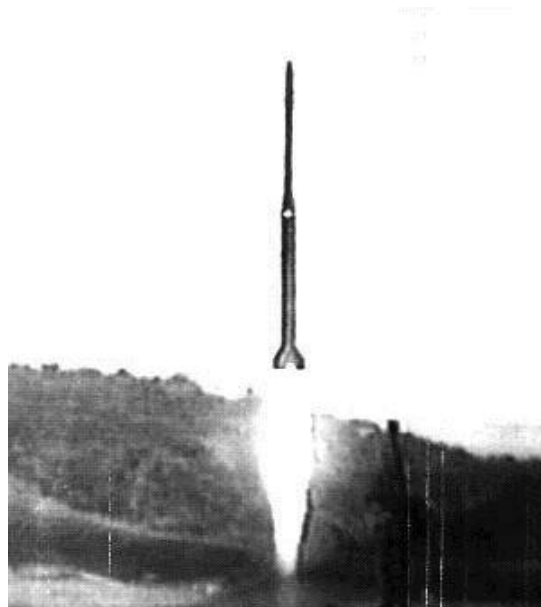


Figure 8-27. TD-1 Launch.

North Korea launched the first medium-range Taepo Dong 1 (TD-1) ballistic missile from the northeastern part of North Korea on 31 August 1998 (see Figure 8-27). The rocket landed in the high seas off the Sanriku coast of Japan, after flying over the Japanese island of Honshu before plunging into the Pacific Ocean. North Korea's test evoked swift condemnation in the region and beyond. Many analysts speculated on Pyongyang's possible motives for conducting its provocative launch at this juncture. North Korea may have been intent on demonstrating a "show of force" in advance of the 50th anniversary of its founding on September 9 and the expected installation of Kim Jong-Il as



"paramount leader" of the secretive Stalinist state. The launch probably had multiple purposes: to serve as an advertisement for the country's missile technology, and to serve as a bargaining chip to win concessions from the US.

On 4 September 1998 the Korean Central News Agency broadcast a report claiming the successful launch of the first North Korean artificial satellite, Kwangmyongsong-1. As of 9 September 1998, US Space Command has not been able to confirm North Korean assertions. US Space Command has not observed any object orbiting the Earth that correlates to the orbital data the North Koreans have provided in their public statements. Additionally, US Space Command did not observe any new object orbiting the Earth in any orbital path that could correlate to the North Korean claims. Lastly, no US radio receiver has been able to detect radio transmissions at 27 megahertz corresponding to the North Korean claims.

Initial reports that Russian military space forces had confirmed that the satellite was in orbit were in error. The North Korean report claimed that North Korean scientists and technicians succeeded in launching an artificial satellite aboard a multi-stage rocket into orbit.

## **NORWAY**

### **Norway and Space Transportation**

Norway's Andoya Rocket Range has conducted approximately 600 sounding rocket launches since 1962 and since 1972 has directly supported numerous ESA scientific experiments. Andoya's high latitude location (approx. 69 degrees N) is ideal for Arctic upper atmospheric research as well as microgravity experiments. In 1993 the Norwegian Space Center in cooperation with the Swedish Space Corporation proposed the establishment of a Polar Satellite Service to launch small (up to 250 kg) spacecraft into LEO orbits. Subsequent decisions by Sweden to cooperate more closely with the Russian Federation have undercut the likelihood that the Polar Satellite Service will commence operations in the near term.

### **Communications-Marcopolo**

Norway became an instant GEO communications operator when in late 1992 Norwegian Telecom purchased the on-orbit Marcopolo 2 spacecraft from the firm of British Satellite Broadcasting. Marcopolo 2 is a Hughes HS-376 class spacecraft launched in August, 1990. The spin-stabilized spacecraft had an initial on-station mass of 660 kg and a payload of five active Ku-band transponders. The spacecraft renamed Thor, is being aided by INTELSAT 702, which is co-located with Thor.

## **PAKISTAN**

### **Pakistan and Satellite Communication Systems**

Although Pakistan has expressed an interest to develop a GEO communications system, the country is still several years away from deploying the first satellite. In the meantime, Pakistan is experimenting with basic store/dump communications relays in LEO. A 50-kg Badr-1 satellite was launched as a secondary payload on the Chinese CZ-2E mission of 16 July 1990. Originally designed for a nearly circular orbit of 400-500 km, Badr-1 was inserted into an orbit of 205 km by 990 km, which led to a natural decay after only 145 days, although contact with the vehicle ceased on 20 August 1990. However, during its short mission, the satellite successfully completed store/dump message tests using 144-146 and 435-436 MHz frequencies.

The Pakistan GEO constellation is being designed with a capacity of 4,800 long distance telephone channels, 2,400 rural circuits, and two direct broadcast television channels in the 14/11 GHz band.

### **Remote Sensing-Badr-B**

Although Pakistan has only operated one small satellite in the country's modest space program has long been oriented toward remote sensing applications. A data processing infrastructure has been established to exploit Earth observation data transmitted by Landsat, NOAA, and SPOT satellites. As a next step, the Space and Upper Atmosphere Research Commission (SUPARCO) is preparing for the commercial launch of a simple Pakistani satellite with Earth imaging capabilities.

The 50-kg Badr-B now in final development will be a cube with side dimensions of 45 cm and a gravity-gradient stabilization system. The project plan envisions a 2-3 year mission for a CCD (charged coupled device) camera in an 800-km, sun-synchronous orbit.

## **PORTUGAL**

### **PoSAT - Portugal and Earth Observation Systems**

Portugal's first satellite, PoSAT-1, was launched on 26 September 1993, as a piggyback payload on an Ariane LEO mission. It was built by the UK's University of Surrey on a SSTL microsatellite bus. One of the central payloads on this 50-kg multi-mission satellite was the Earth Imaging System, consisting of two CCD imagers, two lenses, and a Transputer Data Processing Experiment to provide on-board image processing and data compression. The two different imagers permitted a wide-field capability with 2-km resolution or a narrow-field capability with 200-m resolution. Within a few months the small spacecraft had already returned more than 100 images of the Earth.

## **SAUDI ARABIA**

### **Arabsat - Saudi Arabia and Communication Satellite Systems**

Saudi Arabia is the headquarters of the Arab Satellite Communications Organization which has operated the Arabsat GEO telecommunications system since 1985. With more than 20 member countries, the organization fills a vital role of communications in North Africa and the Middle East for many nations which do not need nor can afford dedicated satellite networks. By the end of 1994, the Arabsat system had been reduced to one spacecraft, but a new generation of satellites was launched in 1996.

The three Arabsat 1 spacecraft are based on the Aerospatiale and MBB Spacebus 100 platform which was also employed for the EUTELSAT 2 series. The primary communications payload consists of two S-band transponders and 25 C-band transponders. The nominal design life was seven years.

Arabsat 1A was launched by Ariane on 8 February 1985 but immediately suffered a solar panel extension malfunction. Arabsat 1B was launched by the U.S. Space Shuttle and was operated near 26 degrees E from June, 1985, until the summer of 1992 when it, too, no longer continued station-keeping operations. Arabsat 1C was launched by Ariane on 26 February 1992.

As a stop-gap measure to maintain network services until the Arabsat 2 spacecraft become available, the organization leased the Canadian Anik D2 spacecraft in 1993. Renamed Arabsat 1D, it is based on a Hughes HS-376 bus and originally carried 24 active C-band transponders. A contract for two Arabsat 2 spacecraft was signed with Aerospatiale in April, 1993. The spacecraft will utilize Aerospatiale's Spacebus 3000 platform to carry 22 C-band transponders (including eight 52 W moderate power transponders) and 12 Ku-band transponders. Arabsat 2 spacecraft has a mass of more than two metric tons on station. The launch of Arabsat 2A and Arabsat 2B will maintain a strong 2-satellite constellation.

## **SINGAPORE**

### **Singapore and Communication Satellite Systems**

During 1994 Singapore Telecommunications teamed with Pasifik Satelit Nusantara of Indonesia and Hughes to form a joint venture for mobile telecommunications services in the Asian theater. From this start, the Asia Pacific Mobile Telecommunications company was born; but the Indonesian partner was replaced with People's Republic of China government investors. Meanwhile, Singapore Telecommunications was examining the possibility of operating its own spacecraft for television broadcasting and telephone services. The spacecraft would likely carry C-band and Ku-band transponders for its principal mission.

## **SOUTH KOREA**

### **South Korea and Satellite Communication Systems**

South Korea's first two spacecraft were based on the UK's Surrey Satellite Technology Ltd. (SSTL) microsatellite design. Kitsat 1 (aka Uribyol 1) and Kitsat 2 (aka Uribyol 2) were carried as piggyback passengers on Ariane flights to LEO. Although neither of the spacecraft was a true communications satellite, both were equipped with a modest store-and-forward messaging capability.

South Korea's long-range goal is to develop its own spacecraft. A step in this direction was taken with Kitsat 2, which was assembled in South Korea from UK components. Relying heavily on a TRW spacecraft bus and engineering expertise, South Korea will assist in the design and manufacture of Komsat which will perform remote sensing as well as serve as a communications relay. The 400-kg spacecraft will be inserted into a 685-km, sun-synchronous orbit in 1999. South Korea has discussed a similar venture with China.

Unable to construct its own GEO communications spacecraft, South Korea contracted with Lockheed-Martin for two 3000 series satellites to be launched in 1995. The Koreasat (aka Mugunghwa) spacecraft will have a mass of about 830 kg on station and will carry 15 Ku-band transponders of which three will be highpower (120 W). Both spacecraft will be positioned at 116 degrees E with expected design lives of 10 years.

### **South Korea and Satellite Communication Systems**

In August 1992, South Korea's first satellite was launched as a piggyback payload on the TOPEX/Poseidon mission. Along with a communications payload, this mission, the KITSAT 1, carried two CDD cameras for Earth photography. The principal national organizations participating in the program were the Korea Advanced Institute of Science and Technology and the University of Surrey, England. KISAT 2 was launched in a similar fashion and orbit on 26 September 1993. Again, the small satellite carried two CDD imaging systems, one of which was of Korean design,

South Korea's latest venture in earth observation will come with the 1999 launch of the Korean Multipurpose Satellite (KOMSAT). This 400-kg satellite--built by TRW-- will carry a 10m resolution CDD imaging system for earth surveys from an altitude of 685 km.

## **SPAIN**

### **Launch Vehicle-Capricornio**

In 1992 Spain's National Institute for Aerospace Technology (INTA) announced plans to develop a small orbital launch vehicle with a payload capacity of up to 100 kg into 600-km polar orbits. Named Capricornio, the launch vehicle is still in the preliminary

design stage, although an initial flight in this decade is desired. To facilitate the development effort, INTA will produce the solid-propellant second stage and purchase a foreign-made solid propellant first stage. The third stage may be either foreign or domestic, liquid- or solid-fueled, although a foreign solid-propellant stage is the leading candidate. The initial launch site may be El Aranosillo near Portugal to be followed by a more capable launch facility in the Canary Islands. Despite funding reductions and schedule delays, the Capricornio program was still officially on-going. Meanwhile, near-term launch needs for Spain's Minisat program will probably be met by the U.S. Pegasus or ESA's Ariane launch vehicles.

### **Communications-Hispasat**

Spain's first GEO communications satellite was launched by Ariane in September, 1992, as Hispasat 1A. The launch of a sister satellite, Hispasat 1B, followed 10 months later. Based on the Eurostar spacecraft bus developed by British Aerospace and Matra Marconi, Hispasat is designed to support civil, military, and government communications requirements through an array of multi-frequency transponders.

With an on-orbit mass of 1.1 metric tons, the government-owned Hispasat 1A carries 15 active transponders: three X-band with one spare and 12 Ku-band (8 at 55 W. 4 at 110 W) with six spares. A problem with the Spanish-manufactured primary antenna on Hispasat 1A, led Matra Marconi to procure an Aerospatiale antenna for Hispasat 1B. The spacecraft design life is ten years. From its position over the Atlantic Ocean, Hispasat is capable of servicing not only Europe but also North and South America.

## **SWEDEN**

### **Communications-Tele-X**

Originally conceived as the birth of a Scandinavian telecommunications network, including Denmark, Finland, Iceland, Norway, and Sweden, Tele-X now represents a national Swedish asset with greatly reduced objectives and prospects. Launched on 2 April 1989 by Ariane, the Tele-X spacecraft is tailored to cover primarily for Finland, Norway, and Sweden.

Based on the Aerospatiale and MBB Spacebus 300, Tele-X has a design life of up to eight years. The communications payload consists of four Ku-band transponders.

### **Communications-Sirius**

In December, 1993, Sweden followed Norway's lead by purchasing the UK's Marcopolo 1 spacecraft (Norway had acquired Marcopolo 2 in 1992). Re-christened Sirius, Marcopolo 1 was transferred to a position near Tele-X in early 1994. Sirius' payload includes six Ku-band transponders and should function until the end of the decade; Sirius

was launched in 1989 with a 10-year lifetime. Sweden maintains an active communications network.

## **TAIWAN**

### **Communications-Rocsat**

In the early 1990's Taiwan adopted a long-range plan for acquiring technologies related to developing and operating spacecraft. The National Space Program Office was subsequently established to oversee a 15-year program which envisioned the launch of three LEO spacecraft with foreign assistance. The multidiscipline Rocsat program will include telecommunications payloads on at least the first two missions. Rocsat 1 will be built by TRW and will carry a Ka-band communications relay experiment. Rocsat 2 will have a more capable communications payload provided by Integral Systems, Inc. Integral Systems will provide the satellite control facility for the Rocsat program.

## **THAILAND**

### **Communications-Thaicom**

Thailand inaugurated its first national GEO communications network during 1993-1994 with the launches of Thaicom 1 (18 December 1993) and Thaicom 2 (8 October 1994) by Ariane boosters. The spacecraft, based on Hughes HS-376L series, are operated by the Shinawatra Satellite Company of Bangkok under a lease arrangement with the Thai government. Both Thaicom satellites have ten C-band and two Ku-band transponders. The 630-kg spacecraft have a design life of at least 13 years. A Thaicom 3 satellite has 24 C-band and 14 Ku-band transponders.

## **TURKEY**

### **Communications-Turksat**

Turkey had hoped to emulate Thailand by quickly launching two GEO communications satellites to form an "instant" network. Unfortunately, Turksat 1A was lost on 24 January 1994 in an Ariane accident. Turksat 1B was successfully positioned in August of that year. The spacecraft is based on the Aerospatiale Spacebus 2000 series with an on-orbit mass of slightly more than one metric ton. The communications payload consists of 16 Ku-band transponders with an expected operational life of 10 years or more. Turksat 1C will replace Turksat 1A and has an expected life of 13 years.

## **UKRAINE**

### **Ukraine and Space Transportation Systems**

Although Ukraine has no domestic space launch facilities, the former Soviet republic has been producing high quality ballistic missile and launch vehicles for more than 30 years. Its current offerings include the Tsyklon and Zerlaunch vehicle families. Moreover, the Russia Kosmos-3M launch vehicle is derived from the Ukrainian R-14 ballistic missile. Ukraine also hopes to convert some of its other ballistic missiles into new small-capacity launch vehicles and continues to be a prime supplier of components for Russian launch vehicles. The heart of Ukrainian ballistic missile and launch vehicle expertise is the Uzhnoye (Southern Scientific Production Association which evolved from the Yangel Design Bureau).

### **Ukraine and Satellite Communications Systems**

With its considerable space technology experience and expertise gained during the USSR years, Ukraine views the development of a multi-purpose national space program as a logical move and consistent with its military conversion policies. Early on the National Space Agency of Ukraine set telecommunications and remote sensing as its initial objectives. While Ukraine already possessed considerable experience in the latter, via the USSR Okean program, communications satellites had previously been a primarily Russian endeavor.

An early concept by the Ukrainian-Russian company Ariadne envisioned establishing a LEO constellation of small communications satellites which could be launched by Ukraine's Tsyklon booster. Later, government emphasis switched to a GEO communications system which might rely on foreign assistance to develop the spacecraft and which could be launched by the Zenit-3 currently under development. As late as December, 1993, the National Space Agency hoped to launch two, "television and communications" spacecraft manufactured by the Yuzhnoye design bureau by the year 2000. The 1.2-metric-ton spacecraft would be able to service Ku-band needs.

### **Remote Sensing-Okean**

Although the National Space Agency of Ukraine was formed in March 1992, and the country already had expertise in developing full satellite and launch vehicle systems, the country was slow in preparing for its first official national satellite. The situation was remedied in 1995 with the launch of the Sich-1 spacecraft, aka Okean-O. Based on the oceanographic series of spacecraft developed by the Yuzhnoye Scientific Production Association under the USSR regime, Sich-1 is reportedly the last of its kind and will be followed by more advanced Earth observation satellites.

Each Okean spacecraft has a mass of a little more than 1,900 kg, with a payload capacity of 550 kg and is launched from the Plesetsk Cosmodrome by the Tsyklon-3 booster, also made by Yuzhnoye NPO. The spacecraft bus is a three-segmented, vertically

oriented cylinder, three meters tall with a base diameter of 1.4 m and an upper diameter of 0.8 m. Okean's primary structure is pressurized and maintained at normal temperatures to protect the support system and payload electronics housed within. Two small, rotatable solar arrays (1.6 m wide and 2.0 m tall) provide a modest 110-270 W average daily power to the payload. Stabilization is partially provided by a gravity-gradient boom extended from the top of the satellite. At the bottom, four large panels (1.0 m wide and 2.9 m long), attached at 90 degrees intervals, support a number of payload receivers and transmitters. An arrow, 11-m-long radar antenna is fixed to the base of one panel.

Okean spacecraft transmit data in realtime on 137.400 MHz using APT formats similar to that employed by Meteor satellites with a scan rate of 4 lines per second. Data is also stored and retransmitted on 466.5 MHz to the three principal data reception and processing centers at Moscow, Novosibirsk, and Khabarovsk.

The major Okean payload is the real-aperture, side-looking RLS-BO radar operating with a vertically polarized 9.5 GHz frequency. This instrument, developed by the Radio Engineering and Electronics Institute (IRE) in Kharkov, provides not only surface characteristics of land, sea, and ice but also near-surface winds and sub-surface features. The last has proved to be exceptionally effective in determining ice thickness in the polar regions as an aid to naval navigation.

Okean satellites employ both nadir-centered and off-nadir swaths. They also serve as the central node in the Condor system, which collects environmental data from small, remote stations on land, water, or ice. Earlier designs for an Okean-M spacecraft, with dual side-looking radar and other improved Earth observation sensors, have apparently been shelved in favor of a second-generation system now known as the Sich-2 satellite (formerly known as Platform B). Sich-2 will be launched by a Zenit-2 booster into a 650-km, sun-synchronous orbit.



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# *Assignment Questions*

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**Information:** The text pages that you are to study are provided at the beginning of the assignment questions.



# ASSIGNMENT 1

Textbook Assignments: "The Navy in Space," chapter 1, pages 1-1 through 1-29; and  
"U.S. Space Organizations," chapter 2, pages 2-1 through 2-36.

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- 1-1. The primary tactical user of space assets is what military service?
  1. Army
  2. Navy
  3. Marines
  4. Coast Guard
  
- 1-2. Much of the tradition of the U.S. Navy owes its origin to what other country's naval force?
  1. French Navy
  2. British Royal Navy
  3. German Naval Forces
  4. Spanish Sailing Fleet
  
- 1-3. Accurate navigation was possible for the first time due to the convergence of all the following enabling factors EXCEPT which one?
  1. Accurate charts
  2. Celestial tables
  3. Longitude parameters
  4. Precision timekeeping
  
- 1-4. What was the initial mission of the Naval Research Laboratory?
  1. To build communications satellites
  2. To research celestial tables and charts
  3. To determine a common time zone delineator
  4. To blend scientific research with naval requirements
  
- 1-5. The foundation for the operational development of ballistic missile programs was laid by what type of rocket?
  1. Nike
  2. Viking
  3. Mariner
  4. Explorer

- 1-6. What was the United States' first operational satellite system?
1. RECOVER
  2. TRANSIT
  3. EXPLORER
  4. VANGUARD
- 1-7. Constellations of the first satellite system remain in service today and provide which of the following types of information?
1. Fleet communications
  2. Astronomical changes
  3. Intelligence information
  4. All-weather navigational data
- 1-8. What was America's first manned space project?
1. Apollo
  2. Gemini
  3. Mercury
  4. Vanguard
- 1-9. Who were the first Americans (a) to enter space flight, and (b) to orbit the earth?
1. (a) Glenn (b) Shepard
  2. (a) Shepard (b) Schirra
  3. (a) Schirra (b) Carpenter
  4. (a) Shepard (b) Glenn
- 1-10. Yuri Gagarin made the first human space flight on April 12th of what year?
1. 1961
  2. 1960
  3. 1959
  4. 1957
- 1-11. Project Gemini had what initial purpose?
1. To demonstrate the technologies and operations necessary to make a manned lunar landing and safe return
  2. To further scientists' research regarding the inner and outer atmospheres
  3. To propel the first communications satellites into space
  4. To measure how long an astronaut could stay in space

- 1-12. The first U.S. two-man space mission occurred in (a) what year and (b) in what spacecraft?
1. 1. (a) 1963 (b) Mercury 5
  2. 2. (a) 1964 (b) Mercury 7
  3. 3. (a) 1965 (b) Gemini 3
  4. 4. (a) 1966 (b) Gemini 9
- 1-13. In January 1967, a space capsule caught fire on the launch pad. Who were the three astronauts killed in this accident?
1. Ed White, Gus Grissom, and Roger Chaffee
  2. John Young, James Lovell, and Gus Grissom
  3. Ed White, Thomas Mattingly, and Thomas Stafford
  4. Roger Chaffee, William Anders, and Eugene Cernan
- 1-14. Two fatal incidents have occurred in America's space program. Which one occurred (a) on the launch pad, and which one occurred (b) after launch?
1. (a) Apollo CSM (b) Challenger
  2. (a) Challenger (b) Gemini
  3. (a) Gemini (b) Apollo CSM
  4. (a) Skylab (b) Discovery
- 1-15. In 1969, America landed the first man on the Moon. Who was the former naval aviator, X-15 test pilot, and Gemini astronaut who had this honor?
1. Buzz Aldrin
  2. Neil Armstrong
  3. Scott Crossfield
  4. Charles "Pete" Conrad
- 1-16. In addition to providing routine access to space, a reusable spacecraft is capable of accomplishing multiple missions. The space shuttle is uniquely capable of accomplishing which of the following missions?
1. Retrieve satellites
  2. Perform surveillance
  3. Perform reconnaissance
  4. Serve as a permanent space station

- 1-17. The world's first reusable spacecraft was orbited in April 1981 and was known by what name?
1. Enterprise
  2. Discovery
  3. Dinosaur
  4. Columbia
- 1-18. What was the mission designation for the first on-orbit, U.S.-manned, space station?
1. Skylab 1
  2. Skylab 1a
  3. Skylab 2
  4. Skylab 2a
- 1-19. The first orbital test flight of the space shuttle was piloted by what two naval astronauts?
1. Vance Brand and Robert Bigson
  2. John Young and Robert Crippen
  3. Richard Truly and Tom Mattingly
  4. Robert Crippen and Richard Hatch
- 1-20. The Jupiter probe *Galileo* was deployed during what shuttle mission?
1. STS-34 (Atlantis)
  2. STS-36 (Atlantis)
  3. STS-39 (Discovery)
  4. STS-41 (Discovery)
- 1-21. In what shuttle mission time period was the Hubble Space Telescope deployed from the Discovery cargo bay?
1. 22 to 27 November 1989
  2. 09 to 20 January 1990
  3. 24 to 29 April 1990
  4. 15 to 20 November 1990
- 1-22. The scientific probe *Ulysses* was deployed during what shuttle mission time period?
1. 08 to 13 August 1989
  2. 06 to 10 October 1990
  3. 02 to 10 December 1990
  4. 05 to 11 April 1991

- 1-23. Policy, guidelines, and implementation of the U.S. space programs and their related activities are formalized in which of the following documents?
1. National Space Policy
  2. National Defense Policy
  3. National Security Policy
  4. National Joint Service Policy
- 1-24. The responsibility for developing, operating, and maintaining space and space support systems critical to national defense lies with what organization?
1. Department of Defense
  2. Department of the Navy
  3. National Security Agency
  4. Central Intelligence Agency
- 1-25. Within the civilian sector, what agency is responsible for advancing space science, exploration, and space applications?
1. National Security Agency (NSA)
  2. Federal Aviation Administration (FAA)
  3. National Aeronautics and Space Administration (NASA)
  4. National Oceanic and Atmospheric Administration (NOAA)
- 1-26. What is the DOD's primary goal in space?
1. To keep a distant watch on armament movements
  2. To deliver as many communication satellites as possible
  3. To provide transport for various payloads requested by the Armed Services
  4. To provide operational capabilities to ensure that the U.S. can meet national security objectives
- 1-27. The Navy and the Marine Corps have sponsored all of the following space programs EXCEPT which one?
1. Fleet Satellite Communications System
  2. Navy Navigation Satellite System
  3. Naval Space Surveillance Center
  4. Space Surveillance Network

- 1-28. The USSPACECOM is headquartered at what location?
1. Peterson Air Force Base, CO
  2. Houston Control Center, TX
  3. Lowry Air Force Base, CO
  4. Kennedy Space Center, FL
- 1-29. The U.S. Space Command (USSPACECOM) was established in 1985 as a unified command to consolidate military assets affecting U.S. activities in space.
1. True
  2. False
- 1-30. The USSPACECOM is supported by what three component commands?
1. NAVSPACECOM, NASA, and AFSPC
  2. AFSPACECOM, NAVSPACECOM, and NASA
  3. AFSPACECOM, NAVSPACECOM, and SPADOC
  4. NAVSPACECOM, AFSPC, and SMDC
- 1-31. The JCS has assigned to the USSPACECOM all of the following missions EXCEPT which one?
1. Space control
  2. Space support
  3. Space force enhancement
  4. Environmental monitoring
- 1-32. The Cheyenne Mountain Air Force Base is a hollowed-out mountain that houses several space and defense centers. It is located near what city?
1. Colorado Springs, CO
  2. White Sands, NM
  3. Salt Lake City, UT
  4. Cheyenne, WY
- 1-33. The Department of the Navy is specifically assigned which of the following responsibilities that may have unique applications for space systems?
1. Sea-based launch and space support missions
  2. Antisubmarine and mine warfare
  3. Maritime reconnaissance
  4. Sea-based launch and space support missions, antisubmarine and mine warfare, and maritime reconnaissance



- 1-34. Of all satellite signals intelligence output provided to the military, the Navy and the Marine Corps use over what percentage?
1. 25% only
  2. 45% only
  3. 65% only
  4. 85%
- 1-35. The responsibility for providing material, acquisition, and life-cycle support for space systems, C<sup>3</sup>I, and undersea surveillance belongs to what command?
1. SPAWAR
  2. SPADOC
  3. NAVSPACOM
  4. NAVSUPPSYSCOM
- 1-36. The naval component of USSPACECOM is what organization?
1. NAVSPACECOM
  2. NAVSPASURCOM
  3. NAVSPASUBCOM
  4. NAVSPAEROCOM
- 1-37. The naval component of USSPACECOM manages which of the following systems?
1. ROTHRR
  2. NAVSOC
  3. TENCAP
  4. ASPADOC
- 1-38. The Naval Space Command (NAVSPACECOM) has a mission to maintain a constant surveillance of space and to provide satellite data as directed by which of the following authorities?
1. Chief of Naval Operations
  2. Secretary of Defense
  3. Chief of Naval Operations and Secretary of Defense
  4. Chief of Naval Operations, Secretary of Defense, and Secretary of the Navy

- 1-39. In addition to supporting the USSPACECOM as a dedicated sensor in the Worldwide Space Surveillance Network, NAVSPACECOM also serves in which of the following capacities?
1. Alternate NORAD Command Post (ANCP)
  2. Alternate Space Control Center (ASCC)
  3. Alternate Space CORAD Surveillance Center (ASCSC)
  4. Alternate Space Defense Operations Center (ASDOC)
- 1-40. In the north-south direction, NAVSPACECOM's electronic fence can detect objects in space at what maximum height, in nautical miles?
1. 5,000
  2. 10,000
  3. 15,000
  4. 20,000
- 1-41. The NAVSPACECOM fence receivers detect what total number of satellite observations per month?
1. 150,000 only
  2. 500,000 only
  3. 750,000 only
  4. 1,000,000
- 1-42. The only Navy organization that performs all space-related functions, including satellite launch support, orbit insertion, satellite commanding and system monitoring, and network scheduling is known by what name?
1. USSPACECOM
  2. NAVSPACOM
  3. NAVSOC
  4. NRL
- 1-43. An up-to-date catalog of all objects in space is maintained by NAVSPACECOM. This catalog serves as a direct backup to the space object catalog maintained by the USSPACECOM and contains more than what total number of observed objects?
1. 2,000
  2. 5,000
  3. 7,000
  4. 10,000

- 1-44. Uplinks of Navy messages, weather broadcasts, and tactical surveillance intelligence distribution are provided by which of the following organizations?
1. Naval Communications Units
  2. Naval Telecommunications Centers
  3. Naval Electromagnetic Spectrum Centers
  4. Naval Computer and Telecommunications Area Master Stations
- 1-45. The primary responsibility for the development of large spacecraft propulsion systems and launch vehicles, including the Apollo Saturn V Moon rocket, lies with what space center?
1. Goddard
  2. Johnson
  3. Marshall
  4. Stennis
- 1-46. Of the following space centers, which one is responsible for the development and operation of unmanned Earth-orbiting spacecraft, including the Hubble Space Telescope?
1. Goddard
  2. Johnson
  3. Marshall
  4. Stennis
- 1-47. The Deep Space Tracking Network is operated by what entity?
1. Jet Propulsion Laboratory (JPL)
  2. Langley Research Center (LaRC)
  3. Lewis Research Center (LeRC)
  4. Ames Research Center (ARC)
- 1-48. The way was paved for the Magellan radar mapping mission to Venus by missions conducted by what entity?
1. Ames Research Center (ARC)
  2. Lewis Research Center (LeRC)
  3. Langley Research Center (LaRC)
  4. Jet Propulsion Laboratory (JPL)

1-49. Basic research in aeronautics and space technology is conducted at what location?

1. Ames Research Center (ARC)
2. Lewis Research Center (LeRC)
3. Langley Research Center (LaRC)
4. Jet Propulsion Laboratory (JPL)

1-50. Advanced research and development in satellite communications systems is conducted at what location?

1. Jet Propulsion Laboratory (JPL)
2. Langley Research Center (LaRC)
3. Lewis Research Center (LeRC)
4. Ames Research Center (ARC)

1-51. The space shuttle external tank is manufactured and assembled at what NASA facility?

1. Goddard Space Flight Center
2. White Sands Test Facility
3. Michoud Assembly Facility
4. Slidell Computer Complex

## ASSIGNMENT 2

Textbook Assignments: “The Space Environment,” chapter 3, pages 3-1 through 3-19; “Orbital Mechanics,” chapter 4, pages 4-1 through 4-26; and “Launch and Recovery Systems,” chapter 5, pages 5-1 through 5-40.

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2-1. The space environment does NOT impact on humans, spaceflight, or atmospheric boundaries of the Earth.

1. True
2. False

2-2. The Sun rotates on a how many day cycle?

1. 23 days
2. 25 days
3. 27 days
4. 29 days

2-3. A solar cycle is determined by the rise and fall of sunspot frequency, which has what range of activity?

1. 4 years peak to peak
2. 7 years peak to peak
3. 11 years peak to peak
4. 15 years peak to peak

2-4. The aurora that occurs in the northern latitudes of 65° to 70° is known by what name?

1. Aurora Borealis
2. Aurora Africanis
3. Aurora Australis
4. Aurora Polaris

2-5. What are some of the primary hazards in space that can affect spacecraft?

1. Thermal variations, macroscopic bodies, radiation and upper atmosphere density variations
2. Photoelectrons, acceleration, man-made debris, and galactic ions
3. Meteoroids, electrons, weightlessness, and vibration
4. Solar flares, solar particles, photoelectrons, and noise

- 2-6. Proton radiation particles can travel at the speed of light and can reach the Earth and low-Earth orbit in a total of approximately how many minutes?
1. 5
  2. 6
  3. 7
  4. 8
- 2-7. The Earth is protected from space radiation by which of the following elements?
1. Ionosphere and geomagnetic field
  2. Deep atmosphere and Van Allen Belts
  3. Geomagnetic field and deep atmosphere
  4. Ionosphere and Van Allen Belts
- 2-8. Satellites in low Earth orbit (LEO) and low inclination are generally shielded, not by the atmosphere, but by which of the following elements?
1. Van Allen belts
  2. Magnetic field
  3. Ionosphere
  4. Exosphere
- 2-9. With regard to spacecraft charging, even weak discharges may bring about which of the following events?
1. Electronic switching only
  2. Breakdown of thermal switching only
  3. Solar cell and optical sensor degradation only
  4. Electronic switching, breakdown of thermal coatings, and solar cell and optical sensor degradation
- 2-10. The entire assortment of all the solid pieces in interplanetary space is known as what complex?
1. Meteoritic complex
  2. Astronomical complex
  3. Cosmological complex
  4. Intergalactic complex
- 2-11. What is a particle while it is moving in space called?
1. Meteor
  2. Meteoroid
  3. Meteorite
  4. Micrometeorite

- 2-12. What is a particle departing space and leaving a glowing trail as it burns up in the atmosphere called?
1. Meteor
  2. Meteoroid
  3. Meteorite
  4. Micrometeorite
- 2-13. The environmental stress level which a space system can survive is known as what attribute?
1. Armoring
  2. Bunkering
  3. Hardness
  4. Survivability
- 2-14. When describing nuclear weapons, one kiloton of TNT is defined to be how many calories?
1. 10,000 (10 thousand or  $10^3$ )
  2. 10,000,000 (10 million or  $10^6$ )
  3. 10,000,000,000 (10 billion or  $10^9$ )
  4. 10,000,000,000,000 (10 trillion or  $10^{12}$ )
- 2-15. What is DoD's only space "weather forecasting" squadron?
1. VQ-2 Detachment Athens, Greece
  2. 7<sup>th</sup> SOP Cape Canaveral Air Force Station, Florida
  3. VR-24 Detachment Rota, Spain
  4. 55SWXS Schreiver AFB, Colorado
- 2-16. The study of trajectories and orbits of stars and planets is called celestial mechanics. What term refers to the study of the trajectories and orbits of man-made objects in space?
1. Celestial reckoning
  2. Orbital mechanics
  3. Celestial navigation
  4. Orbital navigation

- 2-17. One of the earliest known attempts to describe the location of the planets, the Sun, the Moon, and their motions with respect to each other was made by what early astronomer/mathematician?
1. Ptolemy
  2. Aristotle
  3. Pythagoras
  4. Aristarchus
- 2-18. Who was the early astronomer who deduced that the closer a planet is to the Sun, the greater its orbital speed?
1. Brahe
  2. Ptolemy
  3. Copernicus
  4. Aristarchus
- 2-19. The provision of gravitational attraction to the satellite to keep the satellite in its elliptical orbit is known as what law?
1. Law of Areas
  2. Law of Inertia
  3. Law of Ellipses
  4. Law of Harmonics
- 2-20. The farther a satellite is from the Earth, the longer it will take to complete its orbit, the greater the distance it will travel, and the slower its average speed is known as what law?
1. Law of Areas
  2. Law of Inertia
  3. Law of Ellipses
  4. Law of Harmonics
- 2-21. Who was the first scientist to develop and use a telescope?
1. Copernicus
  2. Aristotle
  3. Galileo
  4. Kepler



- 2-22. Which of the following statements best describes Newton's First Law of Motion?
1. There is an equal and opposite reaction for every action
  2. Each planet moves in an elliptical orbit with the Sun at one focus and the other focus empty
  3. Any two objects in the universe attract each other with a force directly proportional to the product of their masses
  4. A body in motion will keep moving at the same speed and in the same direction unless acted upon by an external force
- 2-23. The formula  $F=G*(m_1*m_2)/d^2$  describes what law?
1. Law of Universal Gravitation
  2. Law of Action and Reaction
  3. Law of Harmonics
  4. Law of Inertia
- 2-24. For an object to achieve orbit, it must be projected above the Earth's atmosphere, which extends approximately what total number of miles?
1. 40
  2. 50
  3. 60
  4. 70
- 2-25. When an object's burnout velocity results in an elliptical orbit, the orbital point farthest from the center of the Earth is referred to by what name?
1. Apogee
  2. Perigee
  3. Bolide Point
  4. Equilibrium
- 2-26. What six parameters form the orbital set and establish the size, shape, and orientation of an orbit in space?
1. Semi-Major Axis; Time; Prograde; Retrograde; Eccentricity; and Inclination
  2. Inclination; Time; Semi-Major Axis; Right Ascension of the Ascending Node; Argument of Perigee; and Eccentricity
  3. Eccentricity; Retrograde; Equatorial Angle; Prograde; Polar Angle; and Argument of Perigee
  4. Right Ascension of the Ascending Node; Eccentricity; Inclination; Time; Semi-Major Axis; and Prograde

- 2-27. To orient the orbital plane with respect to the Earth, what factor is used?
1. Time
  2. Perigee
  3. Inclination
  4. Eccentricity
- 2-28. To locate a satellite in space, what coordinate system is used?
1. Topocentric
  2. Geocentric
  3. Geographic
  4. Orbital
- 2-29. Locating reference systems are classified as what two basic types?
1. Geographic and Inertial
  2. Orbital and Non-Inertial
  3. Inertial and Non-Inertial
  4. Geocentric and Topocentric
- 2-30. Regarding mission planning and the subsequent design of a satellite, which of the following facets is one of the most restrictive?
1. Satellite velocity
  2. Satellite inclination
  3. Atmospheric conditions
  4. Total launch environment
- 2-31. Since the Earth rotates from West to East, all points on the Earth's surface have what type of velocity?
1. Westward
  2. Eastward
  3. Southward
  4. Northward
- 2-32. When a satellite is launched into space, it typically must change its orbit at least how many times to perform its mission?
1. One
  2. Two
  3. Three
  4. Four

- 2-33. In satellite mission planning, which of the following factors is critical to mission life?
1. Fuel consumption
  2. Food consumption
  3. Congeniality of crew
  4. Comfort of working spaces
- 2-34. What are the two encompassing types of plane maneuvers?
1. In-plane and out-of-plane
  2. Eccentricity and in-plane
  3. Out-of-plane and inclination
  4. Right ascension and Left ascension
- 2-35. A two-impulse maneuver between two coplanar orbits is known as what type of movement?
1. Bakal Movement
  2. Hohmann Transfer
  3. Heimlich Maneuver
  4. Intra-orbital Impulse
- 2-36. A satellite's ground track is formed by what factor?
1. The right angle of the Earth's surface and a perpendicular line between the Earth's center and the satellite
  2. The intersection of the Earth's surface and a line between the Earth's center and the satellite
  3. The parallel of the Earth's Equator as the satellite passes overhead
  4. The satellite's changing of its orbital plane as it encircles the Earth
- 2-37. The field of view of a satellite is defined as the area of the Earth's surface that is in view from that satellite at any given time.
1. True
  2. False
- 2-38. A satellite in an orbit between 150 and 800 miles above the Earth is said to be in what type of orbit?
1. Elliptical
  2. Geosynchronous
  3. Semi-synchronous
  4. Low Earth orbit

- 2-39. A satellite placed in a low-inclination circular orbit at an altitude of approximately 19,300 nautical miles will have an angular velocity exactly equal to that of the
1. Moon
  2. Earth
  3. stratosphere
  4. magnetosphere
- 2-40. A Molniya orbit is also known as what type of orbit?
1. Low-Earth circular
  2. Sun-synchronous
  3. Geosynchronous
  4. Elliptical
- 2-41. When NASA wishes to place a satellite in space that will allow a user to receive signals from more than one satellite at any time, the satellite is launched into what type of orbit?
1. Geosynchronous
  2. Sun-synchronous
  3. Semi-synchronous
  4. Low-Earth Circular
- 2-42. The apogee of a low-Earth orbit is circularized and decreased by what factor?
1. Electromagnetic forces
  2. Earth's asymmetry
  3. Atmospheric drag
  4. Radiation
- 2-43. Newton's Law of Universal Gravitation indicates that there is what?
1. Ionized gas in outer space
  2. Attraction between all objects and bodies in the universe
  3. Entrapment of electrons and protons in the Earth's magnetic field
  4. Collision of Earth's magnetic field with the orbiting satellite
- 2-44. The early DOD families of launch vehicles were developed from ballistic missile technology.
1. True
  2. False

- 2-45. In selecting the best launch vehicle, NASA and DOD base their choices on all of the following factors EXCEPT which one?
1. Size
  2. Weight
  3. Orbit desired
  4. Mission duration
- 2-46. U.S. space-launch capability was severely affected in 1986 by which three of the following events?
1. Explosion of Challenger; failure of a Delta vehicle; and reduction in funding by Congress
  2. Explosion of a Titan vehicle; explosion of a Delta vehicle; and lack of standby naval ships
  3. Reduction in funding by Congress; decrease in launch pad facilities; and engineering defects in the shuttles
  4. Explosion of Challenger; explosion of a Titan vehicle; and failure of a Delta vehicle
- 2-47. As a result of events in 1986, which of the following decisions was made?
1. To use only Titan launch vehicles
  2. To phase out the use of expendable launch systems
  3. To depend more on the mixed fleet approach
  4. To rely solely on the space shuttle as the single launch vehicle
- 2-48. Which of the following sites is NASA's choice for polar launches?
1. Wallops Island
  2. Kennedy Space Center
  3. Johnson Space Center
  4. Vandenberg Air Force Base
- 2-49. Due to the launch site's azimuth range and latitude and the Earth's rotation for equatorial and geosynchronous orbits, the best location for maximizing the lift capability of a launch vehicle is what site?
1. Wallops Island
  2. Kennedy Space Center
  3. Vandenberg Air Force Base
  4. Edwards Air Force Base

- 2-50. The Global Positioning System Satellites can be placed in space by which of the following launch vehicles?
1. Atlas II
  2. Redstone I
  3. Delta II
  4. Echo I
- 2-51. The Atlas launch vehicle was used as a booster to launch satellites, space probes, and early Project Mercury spacecraft.
1. True
  2. False
- 2-52. The Atlas launch vehicle, used in more than 25 space programs, has launched nearly every one of which of the following types of missions?
1. All Gemini and Apollo missions
  2. All Mercury and Explorer missions
  3. All manned lunar and planetary missions
  4. All unmanned lunar and planetary missions
- 2-53. The Titan IV provides the largest expendable launch capability of what total number of pounds to (a) geosynchronous orbit and (b) low-Earth orbit?
1. (a) 8,000                      (b) 38,000
  2. (a) 9,000                      (b) 38,000
  3. (a) 10,000                     (b) 39,000
  4. (a) 11,000                    (b) 39,000
- 2-54. What deactivated intercontinental ballistic missile was refurbished for use as a space launch vehicle?
1. Atlas I
  2. Atlas II
  3. Titan I
  4. Titan II
- 2-55. The maiden flight of Pegasus marked the first time that an air-launched rocket accomplished which of the following events?
1. Exploded upon launch
  2. Placed a payload in orbit
  3. Carried a monkey into space
  4. Launched a foreign communications satellite

- 2-56. Designed to be launched in flight from the wing of a NASA B-52 aircraft, Pegasus offers a flexible, low-cost, and more-efficient alternative to placing satellites of what maximum weight into low-Earth orbit?
1. 500 pounds
  2. 900 pounds
  3. 1,200 pounds
  4. 1,500 pounds
- 2-57. The requirements for Taurus, part of DARPA's Standard Small Launch Vehicle Program, includes which, if any, of the following characteristics?
1. It is best suited for scientific study of micrometeorites
  2. It has full launch system ground transportability
  3. It uses an Atlas booster
  4. None of the above
- 2-58. The decision to reuse spacecraft and launch vehicles was made for which of the following long-range goals?
1. To lower costs only
  2. To make space flight more routine only
  3. To lower costs and to make space flight more routine
  4. To attract more civilian astronauts due to spacecraft reliability
- 2-59. The space shuttle is capable of which of the following uses?
1. Repair of satellites and their redeployment
  2. Conduct of scientific experiments and astronomical studies
  3. Return of spacecraft to Earth for reuse
  4. All of the above
- 2-60. The Enterprise demonstrated that it could fly in the atmosphere and land without power in gliding flight. However, it was not designed for space flight and today is the property of what organization?
1. U.S. Air Force
  2. Kennedy Space Center
  3. Smithsonian Institution
  4. NASA Command Control Center
- 2-61. NASA named the first four orbiters after famous exploration sailing ships.
1. True
  2. False

- 2-62. The space shuttle is comprised of four primary components, including the orbiter, two solid rocket boosters, and what other component?
1. A launch pad erector
  2. An external fuel tank
  3. An internal fuel tank
  4. A ground transport "crawler"
- 2-63. The crew module of the space shuttle is divided into a total of how many primary sections?
1. One
  2. Two
  3. Three
  4. Four
- 2-64. The orbiter has the capability to transport a payload weighing a maximum of how many pounds (a) into orbit and (b) upon its return to Earth?
1. 1. (a) 10,000 (b) 25,000
  2. 2. (a) 30,000 (b) 25,000
  3. 3. (a) 55,000 (b) 32,000
  4. 4. (a) 76,000 (b) 32,000
- 2-65. After launch of the space shuttle, which of the following events occur?
1. The external fuel tank and the solid rocket boosters are recovered for reuse
  2. The solid rocket boosters are jettisoned and only the external fuel tank is retrieved for reuse
  3. The external fuel tank breaks apart and only the solid rocket boosters are recovered for reuse
  4. The solid rocket boosters and the external fuel tanks are jettisoned, after which they burn up in the atmosphere
- 2-66. During the ignition sequence, which of the following events occur?
1. The solid rocket boosters and the shuttle's main engines ignite simultaneously
  2. The shuttle's main engines are started only after the solid rocket boosters have fired and reach a preset thrust level
  3. The solid rocket boosters are fired after the shuttle reaches a certain mile mark in space
  4. The solid rocket boosters are fired only after the shuttle's main engines have started and reach a preset thrust level



- 2-67. Before performing work outside the shuttle orbiter, an astronaut must breathe pure oxygen for at least what number of hours to remove nitrogen from the blood?
1. 1
  2. 2
  3. 3
  4. 4
- 2-68. The Orbital Maneuvering System (OMS) engines on the orbiter are used for which of the following reasons?
1. To circularize the shuttle's orbit
  2. To complete insertion into Earth orbit
  3. For any major velocity changes
  4. All of the above
- 2-69. The orbiter's on-orbit velocity is approximately how many statute miles per hour?
1. 15,225
  2. 16,322
  3. 17,322
  4. 18,225

## ASSIGNMENT 3

Textbook Assignments: "Space Systems Architecture," chapter 6, pages 6-1 through 6-27; "Naval Tactical Use of Space," chapter 7, pages 7-1 through 7-41; and "Foreign Space Programs," chapter 8, pages 8-1 through 8-46.

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- 3-1. Spinning spacecraft are normally limited to which of the following types of antenna beamshapes?
  1. Elliptical or round
  2. Hemi-omni or elliptical
  3. Spherical or omnidirectional
  4. Altitudinal or longitudinal
- 3-2. A spacecraft's command system has which of the following purposes as its primary purpose?
  1. To enable the spacecraft to maintain a stable attitude in order for it to use higher gain antennas
  2. To permit the spacecraft to be reconfigured in response to radio signals
  3. To determine the status of the spacecraft and its operating environment
  4. To react to an external event or stimulus
- 3-3. To determine the status of a spacecraft and its operating environment, which of the following functions is used?
  1. Data processing
  2. Command processing
  3. Storage processing
  4. Telemetry processing
- 3-4. Thermal control devices fall into what two categories?
  1. Solar and nuclear
  2. Passive and active
  3. Chemical and electrical
  4. Structural and mechanical

- 3-5. A spinning spacecraft uses a positioning sensor that is known by what term?
1. Sun sensor
  2. Star scanner
  3. Earth sensor
  4. Star tracker
- 3-6. Because space is not a perfect vacuum, which of the following natural factors can affect the attitude of a spacecraft?
1. Environmental
  2. Physiological
  3. Operation
  4. Design
- 3-7. Of the following functions, which one is the ground segment's primary function?
1. Tracking and monitoring
  2. Command and control
  3. Post-launch testing
  4. Special operations
- 3-8. The Navy first used the Moon to pass messages between ships at sea and shore stations in what decade?
1. 1950's
  2. 1960's
  3. 1970's
  4. 1980's
- 3-9. Also known as carrier waves, what are the four types of electromagnetic waves?
1. Sky, user, ground, and space
  2. User, space, direct, and pulse
  3. Ground, sky, space, and direct
  4. Microwave, macrowave, sky, and ground
- 3-10. A radio wave propagation path that has limited range, line-of-sight communications is known by which of the following terms?
1. Sky wave
  2. Space wave
  3. Ground wave
  4. Direct wave

- 3-11. To provide worldwide communications coverage, the use of what type of radio wave is most appropriate?
1. Sky
  2. Space
  3. Direct
  4. Ground
- 3-12. A communications signal has which of the following two major components?
1. Baseband signal and carrier wave
  2. Carrier wave and transmission rate
  3. Baseband signal and transmission rate
  4. Carrier wave and microwave component
- 3-13. Baseband information is impressed onto a wave for propagation between stations. This wave is known as what type of wave?
1. Analog wave
  2. Digital wave
  3. Carrier wave
  4. Transmitting wave
- 3-14. General modulation techniques include all of the following modulation types EXCEPT which one?
1. Noise
  2. Phase
  3. Frequency
  4. Amplitude
- 3-15. The method of assigning a range of digital values to represent the original analog signal is known by what name?
1. Sampling
  2. Quantization
  3. Amplitude shift keying
  4. Frequency shift keying
- 3-16. The frequency at which a signal is assigned a quantization level is known by which of the following terms?
1. Coding
  2. Transmitting
  3. Sampling
  4. Quantization level

- 3-17. The measure of a system's capability to pass information is represented by which of the following terms?
1. Analog conversion
  2. Digital conversion
  3. Conversion rate
  4. Transmission rate
- 3-18. When a change in a bit state is indicated by a change in the phase of a carrier wave, it is known by which of the following terms?
1. Pulse shift keying
  2. Phase shift keying
  3. Frequency shift keying
  4. Amplitude shift keying
- 3-19. Communications systems consist of a network of transmitters and receivers.
1. True
  2. False
- 3-20. The organizations that apply data generated by a space segment in support of their missions fall under which of the following categories?
1. Sky
  2. User
  3. Space
  4. Ground
- 3-21. Mission requirements of a particular spacecraft are generated by which of the following elements?
1. User
  2. Supplier
  3. Designer
  4. Civilian contractor
- 3-22. Operational requirements of a particular spacecraft are generated by which of the following elements?
1. User
  2. Supplier
  3. Designer
  4. Civilian contractor

- 3-23. Systems requirements of a particular spacecraft are generated by which of the following elements?
1. User
  2. Supplier
  3. Designer
  4. Civilian contractor
- 3-24. For a given space system, the user segment must always be direct access users.
1. True
  2. False
- 3-25. The MILSATCOM systems capabilities used to support DoD C<sup>4</sup>I in Naval operations include which of the following frequency bands?
1. UHF, GBS, SHF
  2. UHF, SHF, EHF
  3. EHF, FLTSAT, GBS
  4. UFO, SHF, EHF
- 3-26. The metamorphosis in the armed forces headed by network-centric warfare is called what?
1. Evolution in military affairs (EMA)
  2. Revolution in military affairs (RMA)
  3. Metamorphosis in military affairs (MMA)
  4. Transformation in military affairs (TMA)
- 3-27. Network-centric warfare is based on what concept, which is composed of the information, sensor and engagement grids?
1. Network
  2. Platform
  3. Battlecube
  4. Infrastructure
- 3-28. Most importantly, network-centric warfare focuses on using which of the following assets as a weapon to assist the warfighter.
1. Sensors
  2. Technology
  3. Grids
  4. Information

- 3-29. Which of the following elements includes actual submarines, ships, and soldiers?
1. Information grid
  2. Sensor grid
  3. Engagement grid
  4. Weapons grid
- 3-30. Which of the following elements overlays weapon systems and sensors?
1. Information grid
  2. Sensor grid
  3. Engagement grid
  4. Weapons grid
- 3-31. Which of the following elements contains radar, space, and acoustic capabilities?
1. Information grid
  2. Sensor grid
  3. Engagement grid
  4. Weapons grid
- 3-32. What scheme, using INMARSAT-B, will be used to put network-centric warfare into motion for the Navy?
1. Global Command and Control System (GCCS)
  2. Joint Tactical Ground Station (JTAGS)
  3. Space-based Infrared Sensors (SBIRS)
  4. Theater Event System (TES)
- 3-33. What communications system replaces the aging FLTSATs?
1. UHF
  2. DSCS
  3. CUDIXS
  4. UFO
- 3-34. What system, launched in 1998, provides service above 65° N latitude?
1. SATCOM
  2. UFO-9
  3. Advanced EHF
  4. Polar EHF

- 3-35. As a follow-on to MILSTAR, what ongoing venture will serve as DoD's primary means of transmitting highly classified information?
1. EHF MILSATCOM
  2. P3I
  3. OTAR
  4. LPI/LPD
- 3-36. Which of the following is a consortium, headquartered in London, England, that provides satellite communications for commercial users?
1. COPERNICUS
  2. INMARSAT
  3. CHALLENGE ATHENA
  4. INTELSAT
- 3-37. What organization, formed under the leadership of the U.S. in 1964, is the largest satellite service provider covering the globe?
1. COPERNICUS
  2. INMARSAT
  3. CHALLENGE ATHENA
  4. INTELSAT
- 3-38. What project was conceived to use commercial satellites for support of tactical air operations, Tomahawk mission planning, and battle damage assessment?
1. COPERNICUS
  2. INMARSAT
  3. CHALLENGE ATHENA
  4. INTELSAT
- 3-39. What was the Navy's initiative to make C<sup>4</sup>I systems responsive to the warfighter?
1. COPERNICUS
  2. INMARSAT
  3. CHALLENGE ATHENA
  4. INTELSAT
- 3-40. In part, the Global Positioning System (GPS) was developed to meet what need?
1. Provide precise at-sea location of aircraft carriers
  2. Provide precise at-sea location of missile submarines
  3. Provide precise time-of-day determination for NASA
  4. Provide precise time-of-day determination for NOAA



- 3-41. A GPS receiver must have clear lines of sight to a minimum of how many space vehicles in order to provide the user accurate position and time data?
1. 2
  2. 3
  3. 4
  4. 5
- 3-42. GPS satellites have a secondary mission to detect which of the following occurrences?
1. Hurricanes
  2. Bird migrations
  3. Fish migrations
  4. Nuclear detonations
- 3-43. The technique of gathering information about target objects through the analysis of data collected by instruments that are not in physical contact with the objects under investigation is known as what type of sensing?
1. Real-time
  2. Electronic
  3. Remote
  4. Infrared
- 3-44. A rock absorbs sunlight during the day and then reradiates heat energy as infrared radiation at night. This is an example of what process?
1. Absorption
  2. Emission
  3. Reflection
  4. Scattering
- 3-45. What term refers to the redirection of radiated energy by particles suspended in the atmosphere?
1. Absorption
  2. Emission
  3. Reflection
  4. Scattering

- 3-46. Most remote sensing systems are designed to monitor radiation from what process?
1. Absorption
  2. Emission
  3. Reflection
  4. Scattering
- 3-47. Which of the following satellite systems is the U.S. government's civilian system that can show deforestation?
1. DMSP
  2. GOES
  3. LANDSAT
  4. POES
- 3-48. Which of the following satellite systems is used by the NOAA for weather forecasting?
1. DMSP
  2. GOES
  3. LANDSAT
  4. TELSTAR
- 3-49. What weather satellites were launched in 1988 and 1990 by the People's Republic of China (PRC)?
1. Feng Yun
  2. Chang Zheng
  3. Fang Hong
  4. China Star
- 3-50. What is the Chinese name for the Long March family of launchers used by the PRC?
1. Feng Yun
  2. Chang Zheng
  3. Fang Hong
  4. Dong Hong
- 3-51. What code name did China use for its series of experimental communications satellites from the late 1970s through the 1980s?
1. ChinaSat
  2. Fang Zheng
  3. Dong Fang Hong
  4. AsiaSat

- 3-52. What Chinese satellite system, established in 1983, had an initial objective to provide a satellite-based TV broadcast network to the country's remote areas?
1. ChinaSat
  2. APStar
  3. Dong Fang Hong
  4. AsiaSat
- 3-53. The PRC and Brazil developed a joint Earth observation spacecraft known as what?
1. SinoSat 1
  2. Feng Yun 2
  3. GLONASS
  4. Zi Yuan CBERS
- 3-54. Japan's space development program is planned and supervised by what advisory committee that reports to the country's Prime Minister?
1. NASDA
  2. SAC
  3. ISAS
  4. H-IIA
- 3-55. Which of the following satellites, launched in 1970, was Japan's first satellite?
1. Baby
  2. Kokubunji
  3. Oshumi
  4. Kappa
- 3-56. Which of the following is a joint project of Japan and the United States to measure the amount and distribution of rainfall in tropical areas?
1. TRMM
  2. NASDA
  3. AMSR
  4. ADEOS
- 3-57. What are the names of the (a) chase satellite and the (b) target satellite used by Japan to conduct experiments in rendezvous-docking and space robotics?
1. (a) HOPE X (b) TDRS
  2. (a) OICETS (b) ARTEMIS
  3. (a) COMETS (b) SELENE
  4. (a) HIKOBOSHI (b) ORIHIME

- 3-58. A total of how many member nations belong to the European Space Agency (ESA)?
1. 6
  2. 10
  3. 14
  4. 18
- 3-59. What launcher-family is considered to be Europe's "space workhorse"?
1. Ariane
  2. Vulcain
  3. Esro
  4. Selene
- 3-60. One of the largest broadcasting systems in the world today has 70 million cable television viewers in Europe, Africa, and the Middle East. It receives analog and digital television channels from what satellite family?
1. INMARSAT
  2. INTELSAT
  3. HOT BIRD
  4. OLYMPUS
- 3-61. The Russian (former Soviet Union) space program started the "space race" in 1957 with the launch of which satellite?
1. Luna 1
  2. Sputnik I
  3. Soyuz
  4. Vostok
- 3-62. Which of the following spacecraft was the first to land on the Moon?
1. Apollo 8
  2. Luna 2
  3. Apollo 11
  4. Luna 3
- 3-63. Who was the first woman to orbit the Earth?
1. Valentina Tereskhova
  2. Sally Ride
  3. Musa Manarov
  4. Christa McAuliffe

- 3-64. Which of the following spacecraft is an unmanned freighter used to service the Russian space stations?
1. Salyut
  2. Progress
  3. Mir
  4. Raduga
- 3-65. The Russian space station Mir remained in orbit for more than fifteen years before deorbiting and burning up over the Pacific Ocean. What was the official translation of the name “Mir”?
1. Commune
  2. Village
  3. Progress
  4. Peace
- 3-66. The scientific satellites known as “Magion” were developed by what country?
1. Czech Republic
  2. India
  3. Israel
  4. Malaysia
- 3-67. What is the name of North Korea’s medium-range ballistic missile?
1. Kwangmyongsong 1
  2. Kim Jong-Il
  3. Pyongyang 1
  4. Taepo Dong 1
- 3-68. Which former republic of the Soviet Union has its own programs for ballistic missiles, launch vehicles, and satellites?
1. Chechnya
  2. Kazakhstan
  3. Ukraine
  4. Uzbekistan

